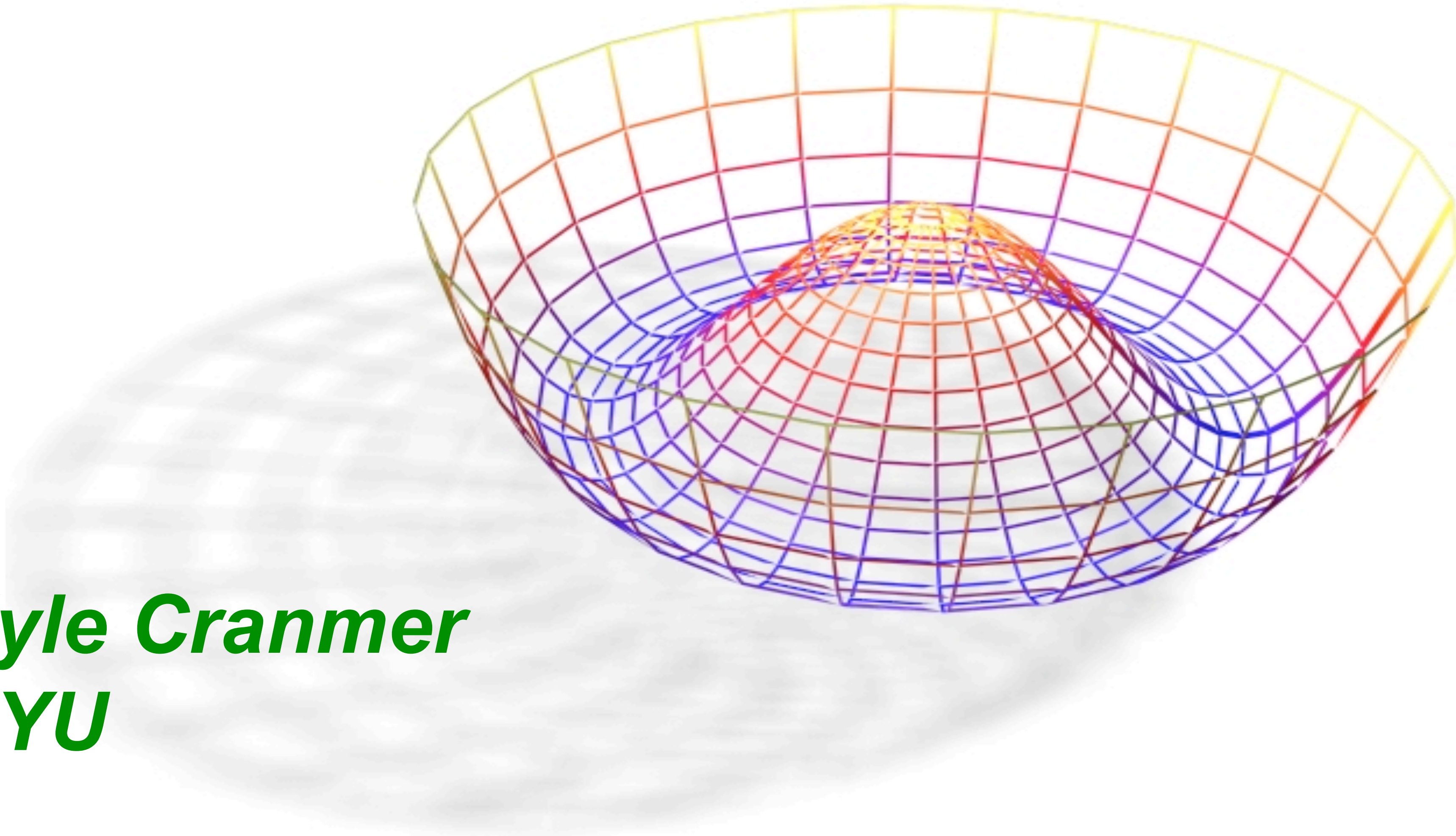
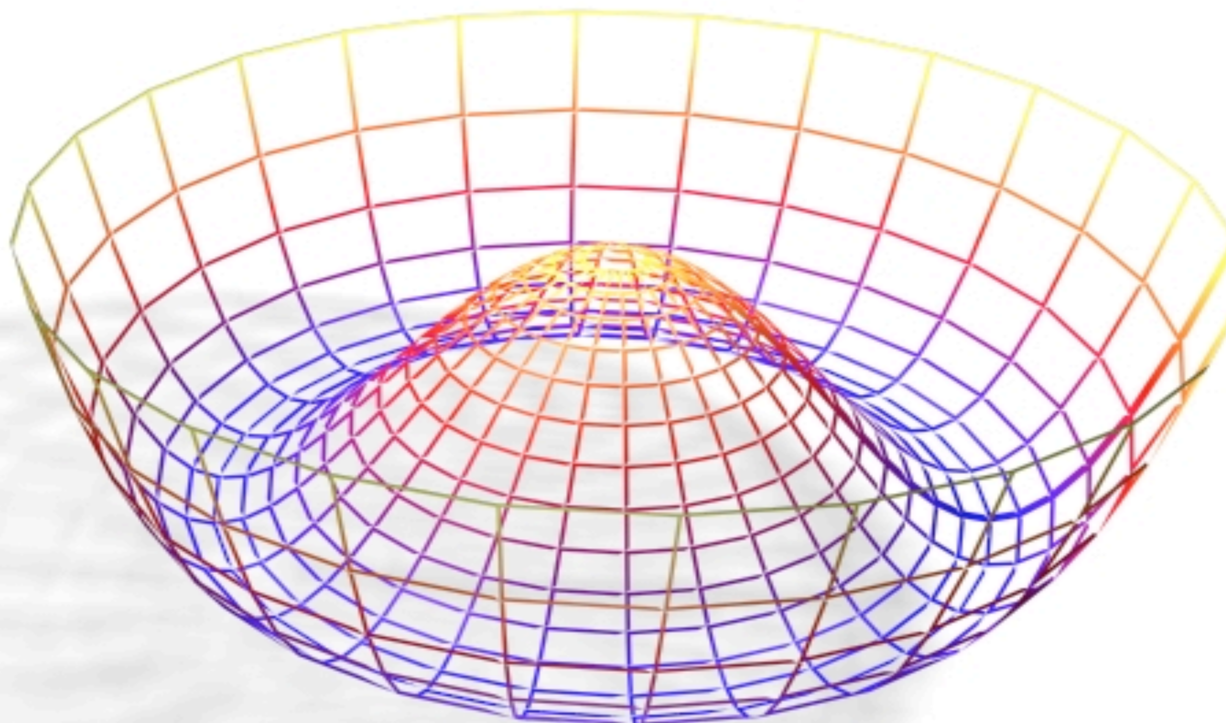
The Truth about Year 1!



Kyle Cranmer
NYU

The Truth about Year 1?

$y\,\bar{t}$  t

Kyle Cranmer
NYU

Overview

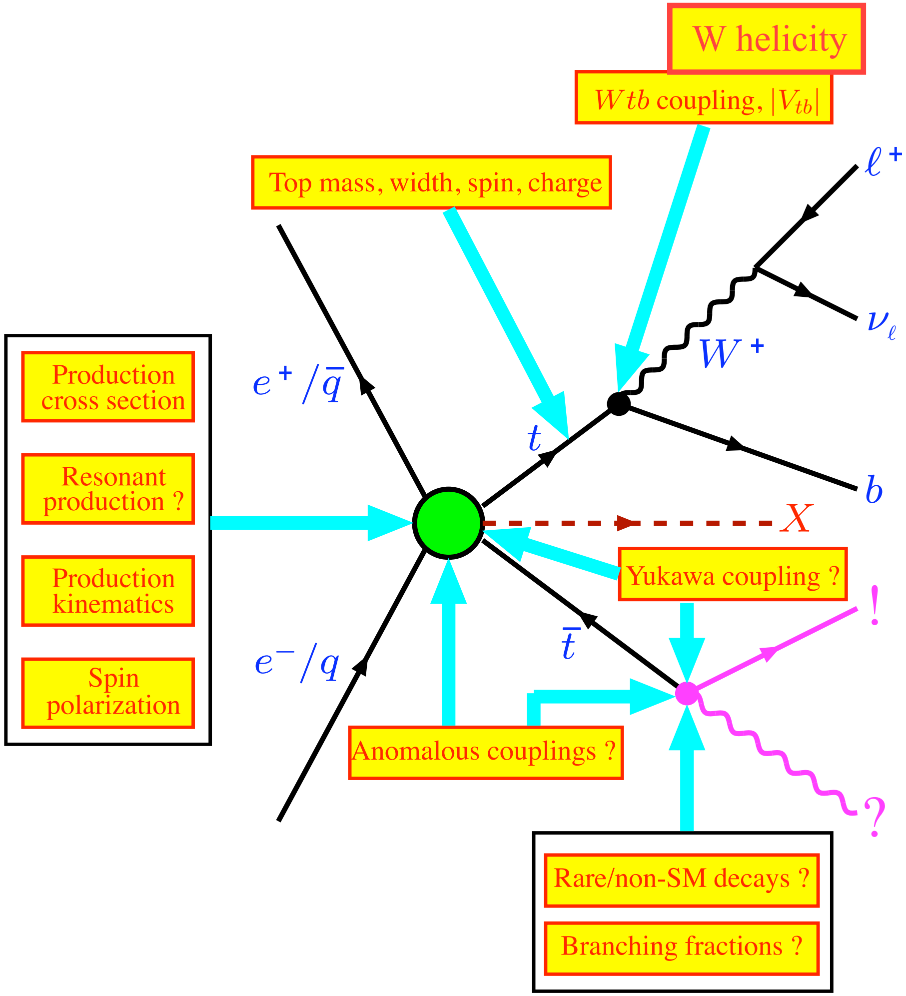
Thanks to Tim, Meenakshi, Florencia, and Alex for the nice talks so far.

I will review the picture of the top at the LHC in the first year (assuming ~100 pb^{-1}) and some results at 1 fb^{-1}

- some details on cross-section measurement and properties

I will also have a few topics aimed at the interaction of theorists and experimentalists

I'll take a lot of results from recent ATLAS studies in "CSC book" (full simulation, 14 TeV, released 12/08)



CERN-OPEN-2008-020
December 2008

Resources

CMS Physics TDR:

- http://cmsdoc.cern.ch/cms/cpt/tdr/

ATLAS CSC Book

- "Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics."
  - CERN-OPEN-2008-020 also on arxiv

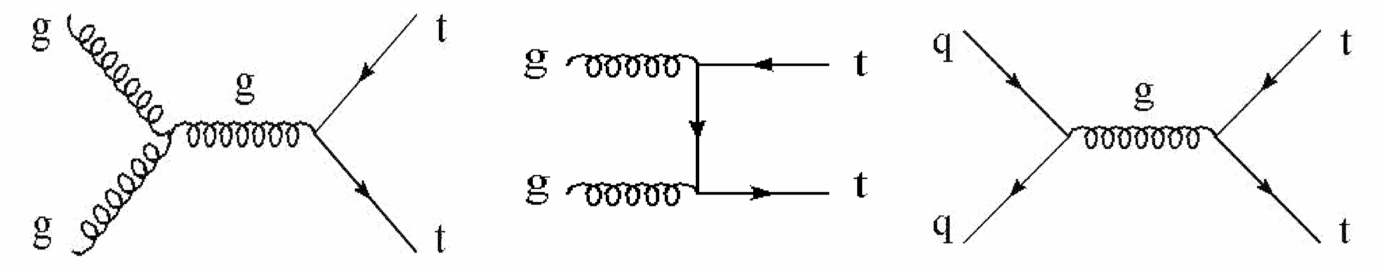
Top Workshop at CERN

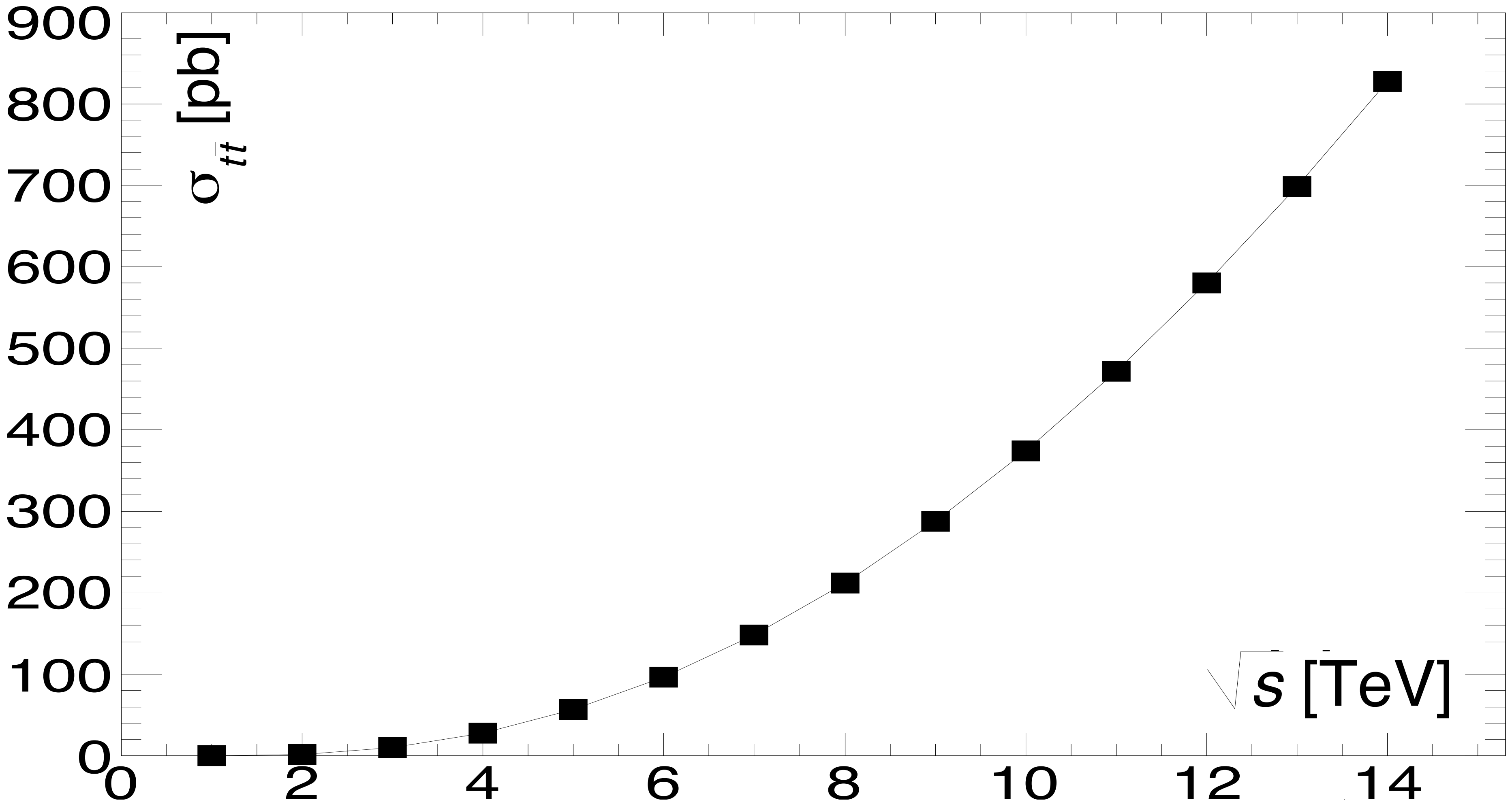
- http://indico.cern.ch/conferenceDisplay.py?confId=62096

International Workshop on Top Quark Physics, La Biodola, Isola d'Elba, Italy, May 2008

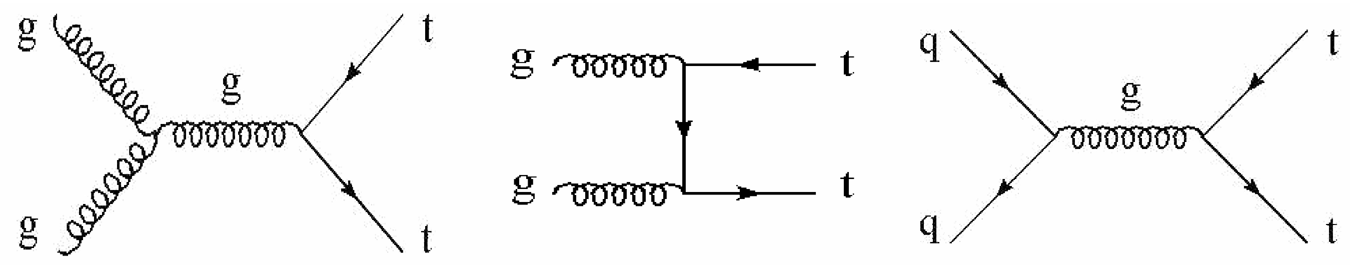
- http://www.slac.stanford.edu/spires/find/hep?cnum=C08-05-18

Quick Reminders:

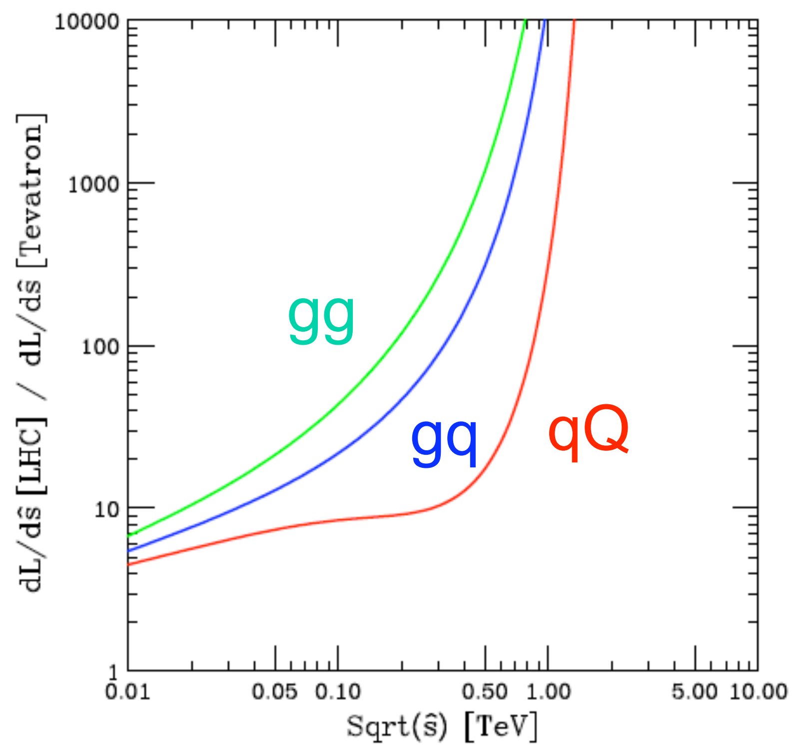


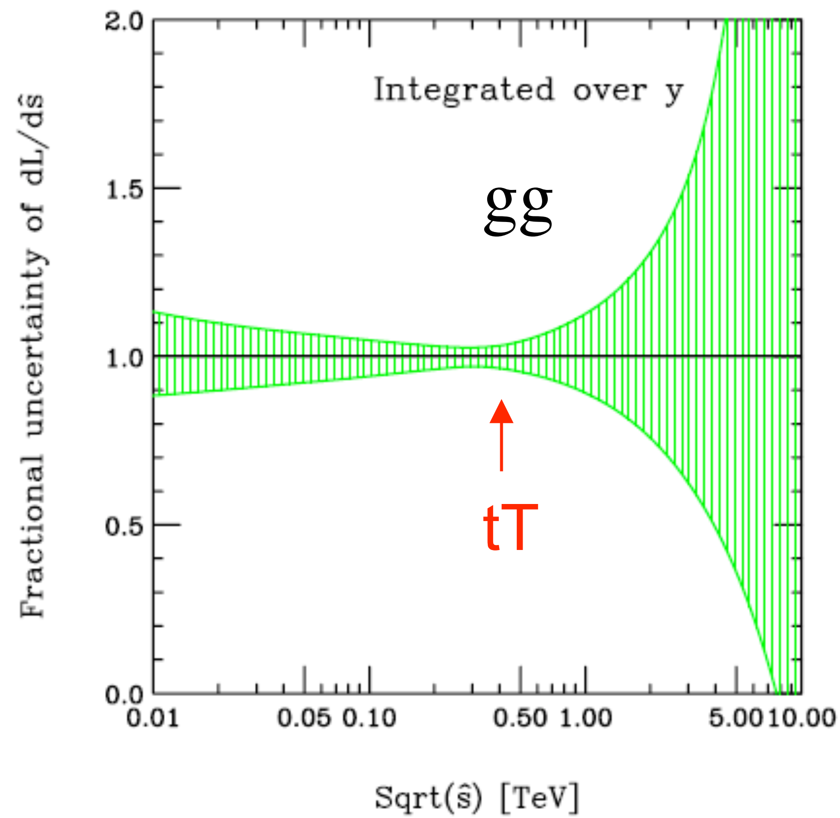


PDFs



85% qQ initial state (Tevatron) vs 90% gluon-gluon initial state (LHC)



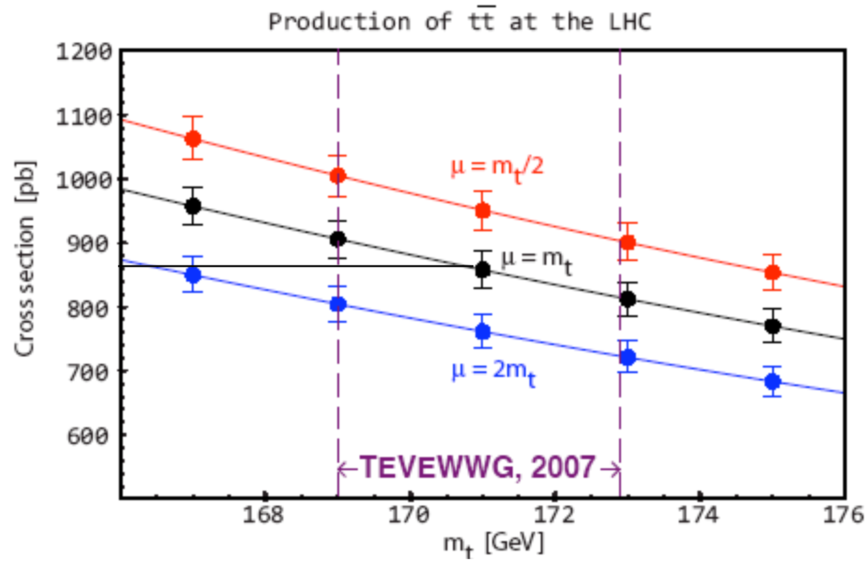


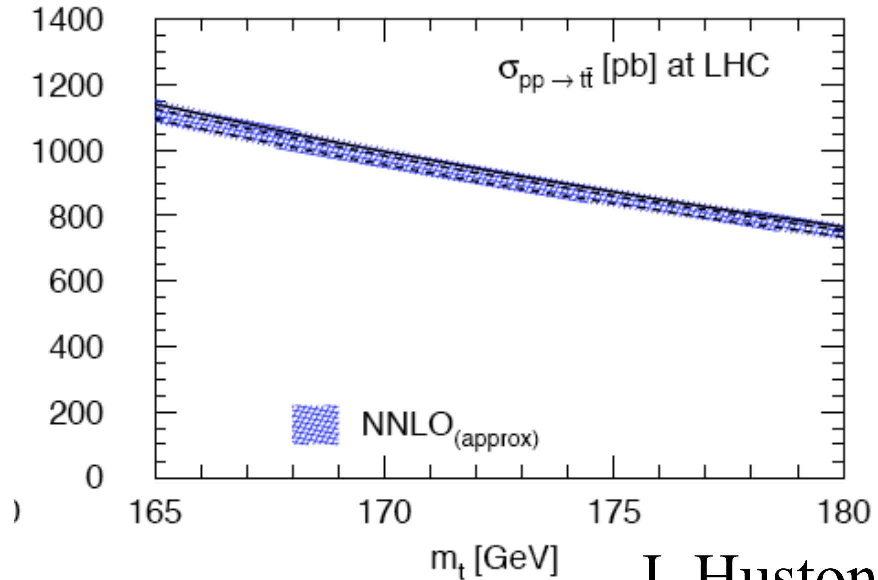
Fortunately, gluon PDF at low x is relatively well known.

Overview on theory uncertainties

Theory uncertainties for tT at LHC

- Note that at NLO with CTEQ6.6 pdf's the central prediction for the tT cross section for $\mu=m_t$ is ~850 pb for 171 GeV (not 800 pb, which it would be if the top mass were 175 GeV); ~880 pb if use effect of threshold resummation
- The scale dependence is around +/-11% and mass dependence is around +/-6%
- Tevatron plans to measure top mass to 1 GeV
  - mass dependence goes to ~+/-3%
- NNLO tT cross section will be finished in (hopefully) near future
  - scale dependence will drop
  - threshold resummation reduces scale dependence to perhaps 3% (Moch and Uwer)
- tT still in worse shape than W/Z, but not by too much
  - and pdf uncertainty is (a bit) smaller



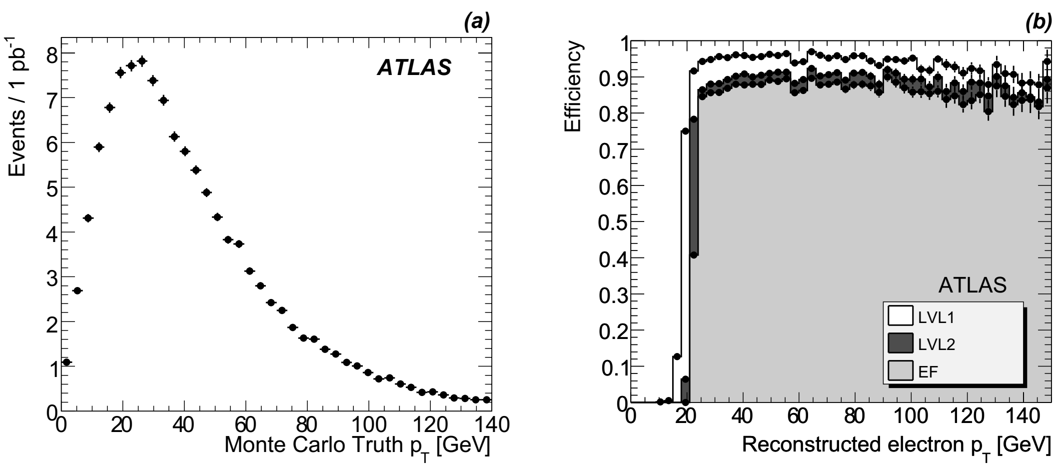


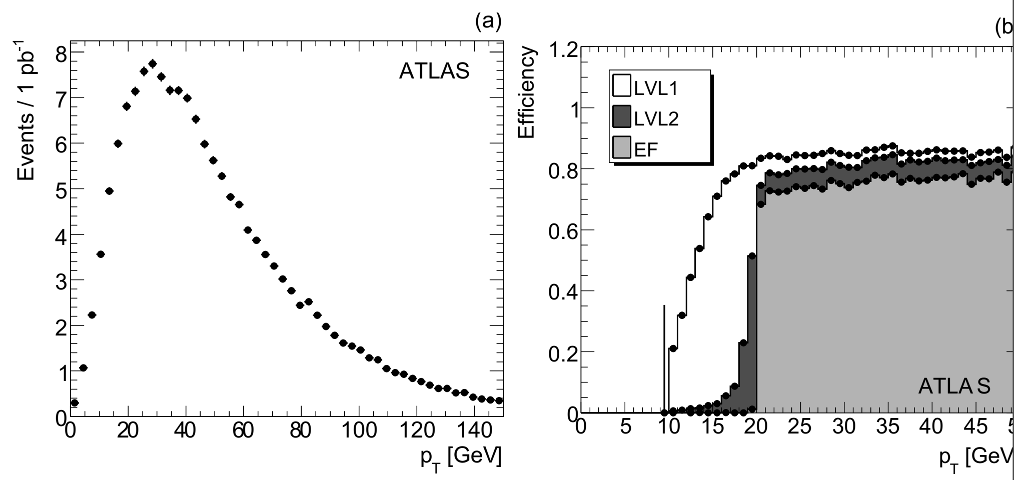
J. Huston

Triggers

The first thing we must do is trigger on the events

- primarily rely on electron or muon triggers
  - some care in defining absolute efficiency or w.r.t. offline selection





Trigger	Compared to Monte Carlo Eff. [%]	Compared to offline selection Eff. [%]
e22i:		
L1 EM18I	74.7 ± 0.5	96.0 ± 0.6
L2 e22i	59.6 ± 0.6	92.7 ± 0.9
EF e22i	52.9 ± 0.6	89.8 ± 1.0
e12i:		
L1 EM7I	83.6 ± 0.4	98.6 ± 0.3
L2 e12i	66.7 ± 0.5	92.6 ± 0.8
EF e12i	63.5 ± 0.5	91.8 ± 0.8

Multi-Jet triggers have been studied for all hadronic channel

Trigger	Signal Efficiency [%]	Relative Background
4j60_2j100_j170	6	0.13
5j45_2j60_j100	16	0.34
6j35_5j45_4j50_3j60	10	0.18

Jet & b-tagging performance

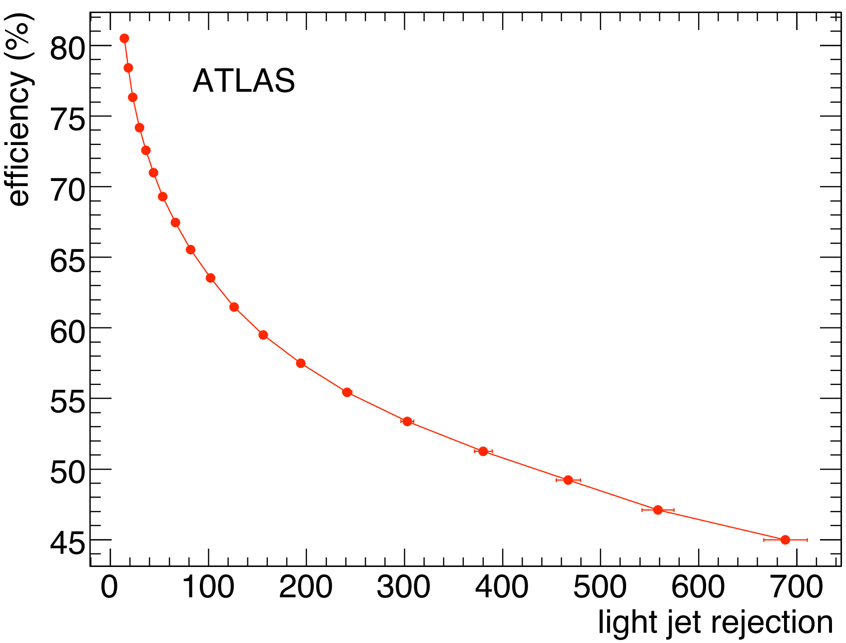
Jet reconstruction and b-tagging performance are clearly crucial experimental issues for top at the LHC

- jet reconstruction and calibration in ATLAS is still developing rapidly (more later)
- several b-tagging algorithms have been developed

How long it will take for these algorithms to converge and their performance to be measured is difficult to say

- we need to know underlying event first
- we need to know the bunch structure & pile up first
- we need to align and calibrate with data

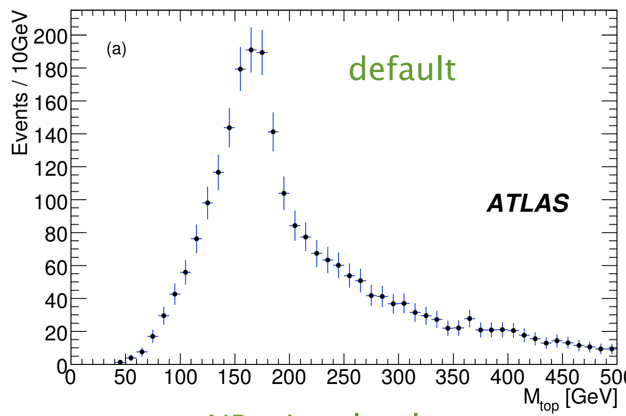
At some point top will be a major tool for us to calibrate our jets and even measure b-tagging efficiencies

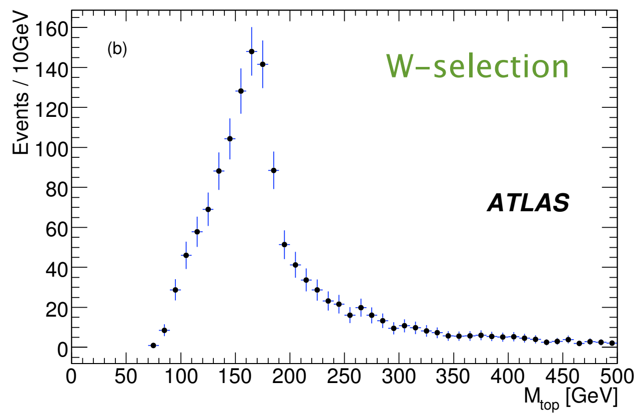


Early Single-lepton top reconstruction

1) Top candidate defined as 3-jet combination with highest pT sum

4) combinatorics reduced, top peak is better defined

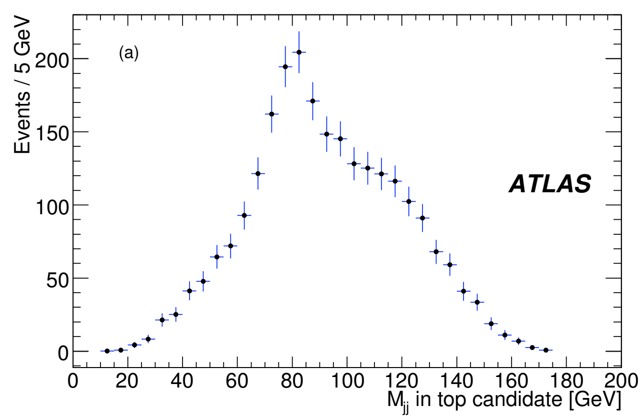


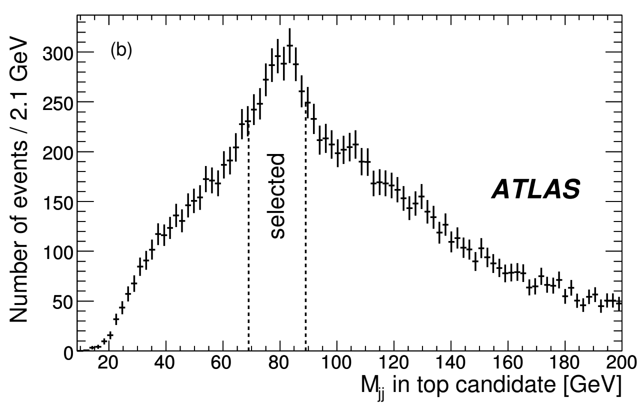


NB: signal only

2) Di-jet mass for pair with highest sum pT shows W peak, but may bias

3) consider all three pairs of jets inside the top, look for W peak





NB: bkg included

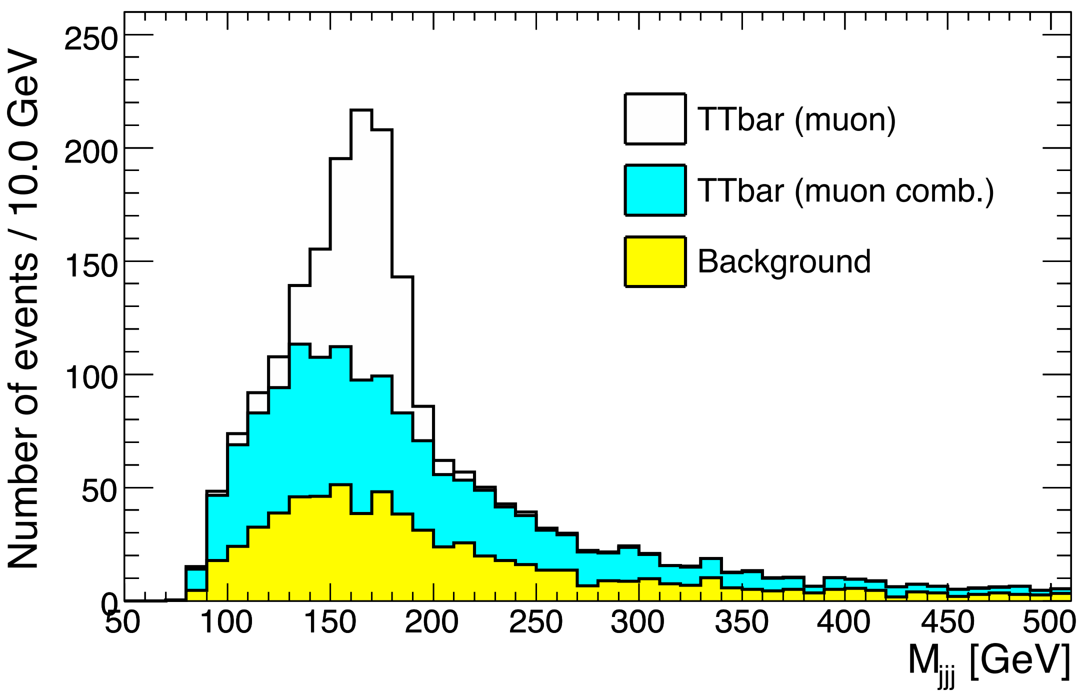
Figure 2: (a): The di-jet combination with highest p_T (left) for the electron analysis. (b): The three di-jet combinations invariant masses among the top-quark candidates in a 100 pb^{-1} event sample for the muon analysis.

Single-Lepton Channels

In the single-lepton channel, a simple "cut and count" analysis can be used to measure the cross-section with as little as 100 pb^{-1}

For our *default* off-line selection the events are required to fulfil the following:

- One lepton (electron or muon) with $p_T > 20$ GeV.
- $\not{E}_T > 20$ GeV.
- At least four jets with $p_T > 20$ GeV.
- Of which at least three jets with $p_T > 40$ GeV.

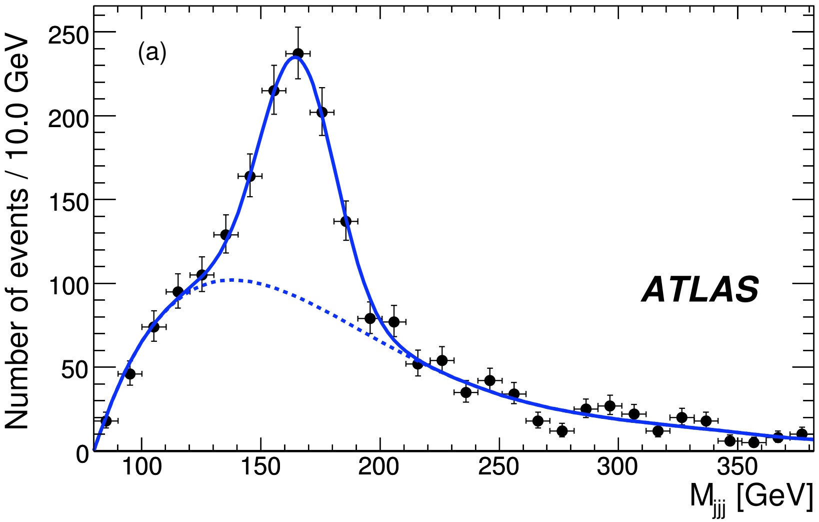


	Muon analysis			
Sample	default	W const.	m_t win	W const. + $\|\eta\| < 1$
$t\bar{t}$	3274	1606	755	386
hadronic $t\bar{t}$	35	17	7	6
W+jets	1052	319	98	47
single top	227	99	25	19
$Z \rightarrow ll$ +jets	84	23	3	2
$W\ b\bar{b}$	64	19	4	4
$W\ c\bar{c}$	26	9	3	0.7
$W\ W$	7	3	0.7	0.7
$W\ Z$	7	3	0.8	0.5
$Z\ Z$	0.7	0.3	0.1	0.0
Signal	3274	1606	755	386
Background	1497	495	143	84
S/B	2.2	3.2	5.3	4.6

Measurement without b-tagging

Two methods considered for early cross-section measurement

- fit M_{jjj} spectrum: sensitive to modeling
- simple counting: sensitive to background prediction
  - results shown for 100 pb^{-1}



Source	Likelihood fit Electron	Muon	Counting method (elec) Default	W const.
Statistical	10.5	8.0	2.7	3.5
Lepton ID efficiency	1.0	1.0	1.0	1.0
Lepton trigger efficiency	1.0	1.0	1.0	1.0
50% more W+jets	1.0	0.6	14.7	9.5
20% more W+jets	0.3	0.3	5.9	3.8
Jet Energy Scale (5%)	2.3	0.9	13.3	9.7
PDFs	2.5	2.2	2.3	2.5
ISR/FSR	8.9	8.9	10.6	8.9
Shape of fit function	14.0	10.4	-	-

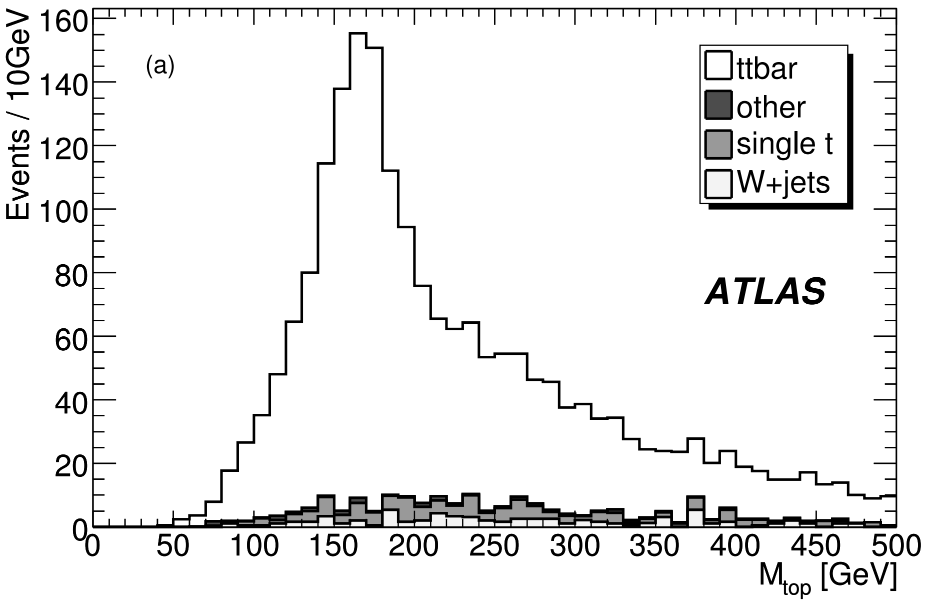
100 pb^{-1}

$$\text{Likelihood method:} \quad \Delta\sigma/\sigma = (7(\text{stat}) \pm 15(\text{syst}) \pm 3(\text{pdf}) \pm 5(\text{lumi}))\%$$

$$\text{Counting method:} \quad \Delta\sigma/\sigma = (3(\text{stat}) \pm 16(\text{syst}) \pm 3(\text{pdf}) \pm 5(\text{lumi}))\%$$

Single lepton, with b-tagging

Finally, we can add b-tagging. Assuming the expected performance at 50-60% tagging efficiency, purity is increased by a factor of ~4.



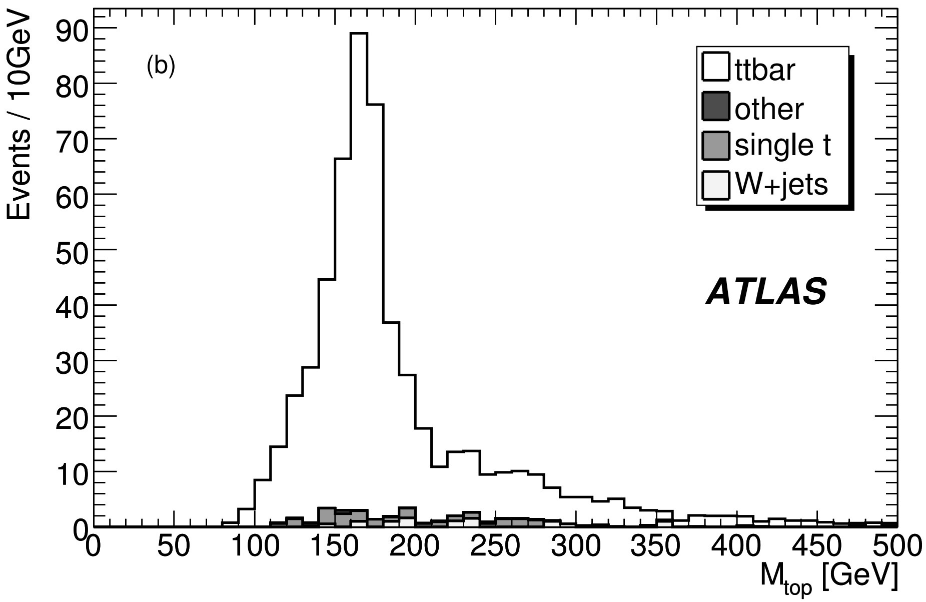
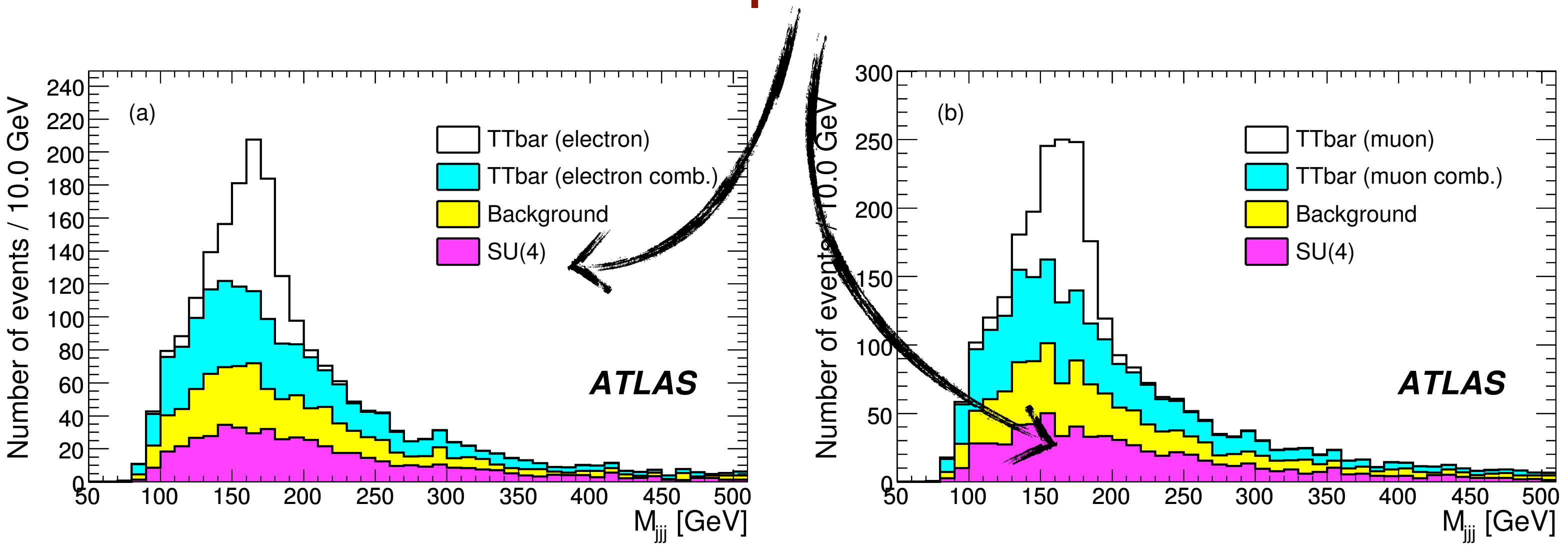


Figure 8: (a): Reconstructed three-jet mass for $t\bar{t}$, single top and W-boson + jet events for the default electron selection, requiring one or two jets tagged as coming from a b-quark. (b): Same distribution for the default selection + the W-boson mass constraint and requiring one or two jets tagged as coming from a b-quark.

If we were so lucky

If we have new physics, it could contaminate the sample

- consider a few mSUGRA points:



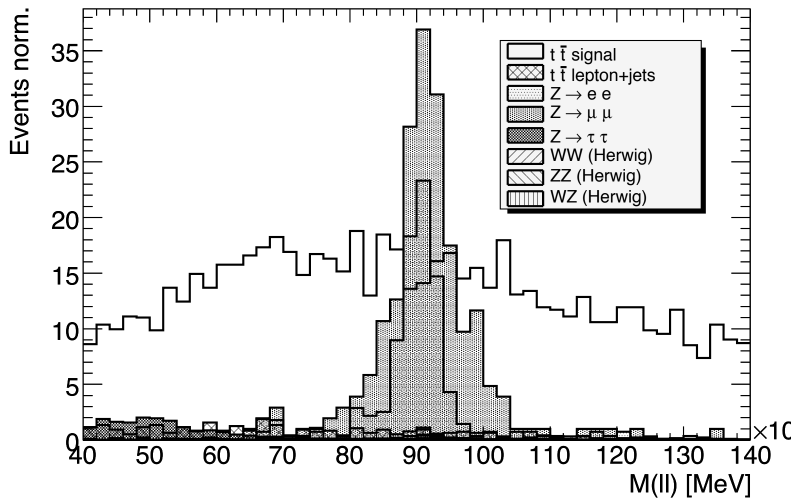
Along similar lines, counting experiments need to use Monte Carlo predictions for backgrounds such as single-top

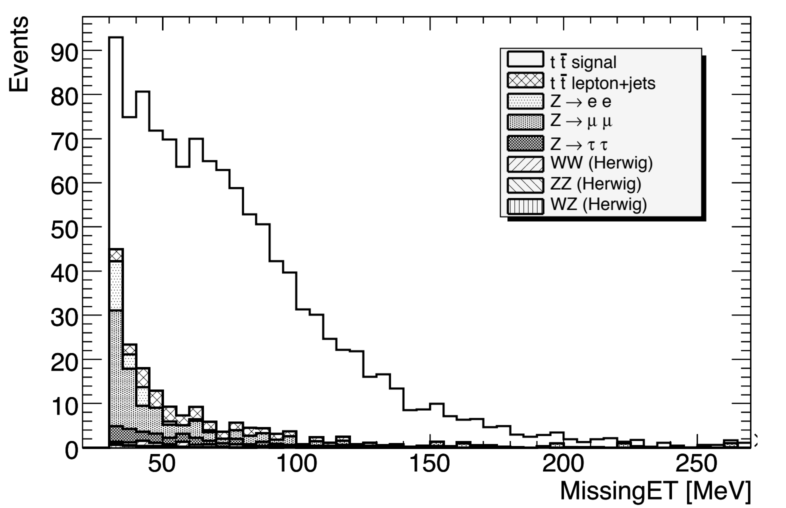
... and data driven backgrounds could have new physics contaminating the control samples.

Dileptonic Channels

In the di-lepton channel, a simple "cut and count" analysis can be used to measure the cross-section with as little as 100 pb^{-1}

- 2 opposite sign leptons and 2 jets pt > 20 GeV
- MET > 30 GeV and remove mll ~ 90 GeV



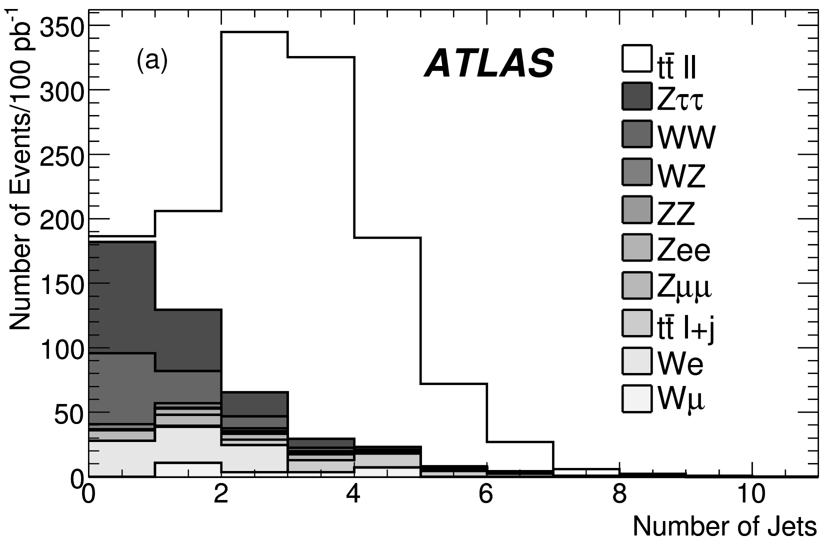


dataset	$e\mu$	ee	$\mu\mu$	all channels
$t\bar{t}$ (signal)	555	202	253	987
ε [%]	6.22	2.26	2.83	11.05
$t\bar{t}$ (bkg)	24	11	4	39
$Z \to e^+e^-$	0.0	9	0.0	20
$Z \to \mu^+\mu^-$	5	0	51	79
$Z \to \tau^+\tau^-$	17	4	6	25
WW	6	2	2	10
ZZ	0	0.2	0.4	0.9
WZ	1	0.6	1	3
$W \to e\nu_e$	7	7	0.0	14
$W \to \mu\nu_\mu$	25	0.0	7	33
single top Wt	0.7	0.5	0.0	1
single top s-chann.	0.0	0.0	0.0	0.1
single top t-chann.	2	0.8	1	4
Total bkg.	86	36	73	228
S/B	6.3	5.6	3.4	4.3

Dileptonic Channels

In the di-lepton channel, a simple "cut and count" analysis can be used to measure the cross-section with as little as 100 pb^{-1}

- The luminosity error dominates, and the uncertainty on that could be as large as 20%
- Assuming a 5% luminosity error, get a ~9% measurement of cross-section in this channel



	cut and count method				likelihood method			
$\Delta\sigma/\sigma$ [%]	$e\mu$	ee	$\mu\mu$	all	$e\mu$	ee	$\mu\mu$	all
CTEQ6.1L set	2.4	2.9	2.0	2.4	0.3	0.4	0.2	0.2
MRST2001L set	0.9	1.1	0.7	0.9	0.2	0.2	0.1	0.2
JES-5%	-2.0	0.0	-3.1	-2.1	-5.4	1.1	4.9	8.3
JES+5%	2.4	4.1	4.7	4.6	7.8	3.9	-4.6	-4.4
FSR	2.0	2.0	4.0	2.0	0.2	0.4	0.0	0.3
ISR	1.1	1.1	1.2	1.1	2.5	1.8	0.0	1.7
parameters-1σ					-3.0	-0.2	-2.1	-1.8
paramterrs+1σ					3.2	0.8	2.0	2.0

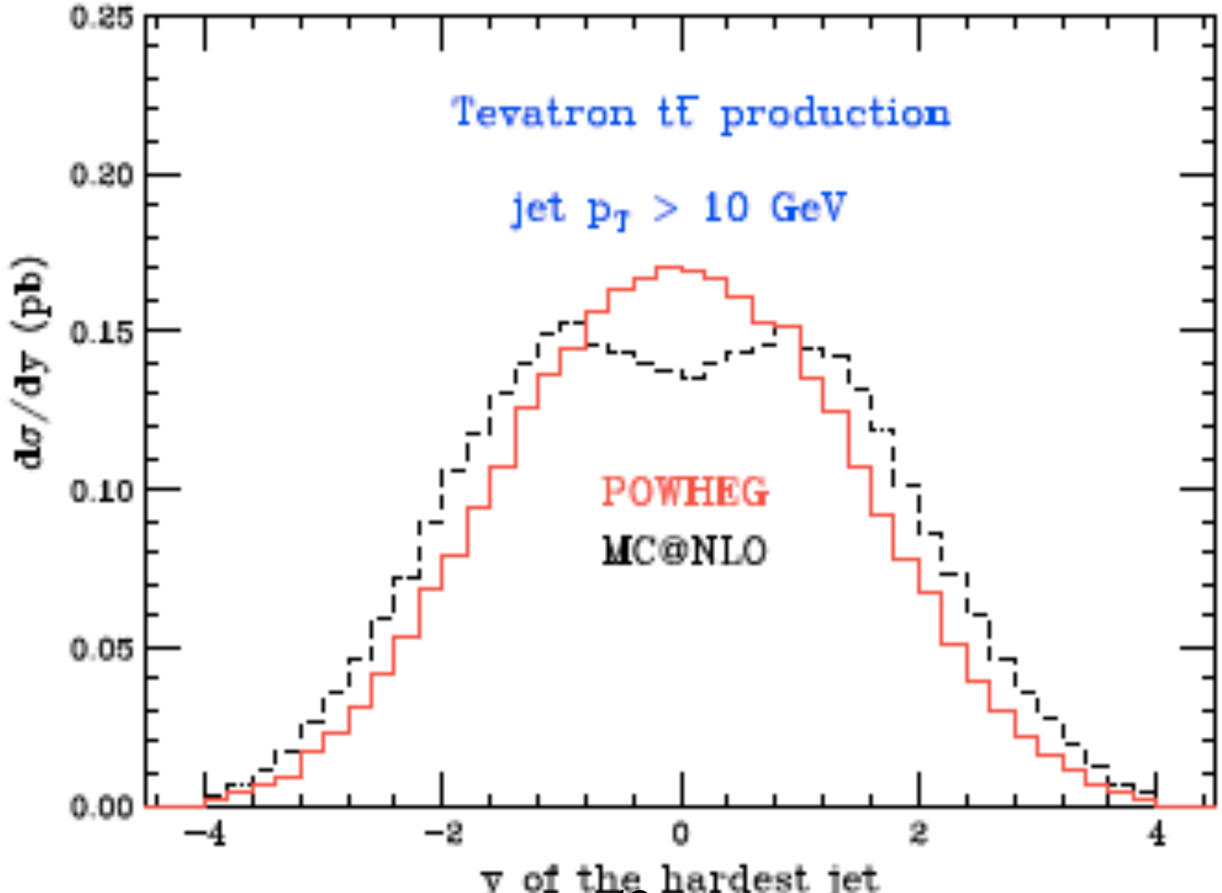
$$\text{Cut and Count method:} \quad \Delta\sigma/\sigma = \quad (4(\text{stat})^{+5}_{-2}(\text{syst}) \pm 2(\text{pdf}) \pm 5(\text{lumi}))\%$$

$$\text{Template method:} \quad \Delta\sigma/\sigma = \quad (4(\text{stat}) \pm 4(\text{syst}) \pm 2.(\text{pdf}) \pm 5(\text{lumi}))\%$$

$$\text{Likelihood method method:} \quad \Delta\sigma/\sigma = \quad (5(\text{stat})^{+8}_{-5}(\text{syst}) \pm 0.2(\text{pdf}) \pm 5(\text{lumi}))\%$$

Miscellaneous point

Can we really make a precise measurement if the acceptance of our jets could be either of these two distributions?



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Single top cross-section

Much more difficult. It requires a more sophisticated analysis, but reasonable measurement with 1 fb^{-1}

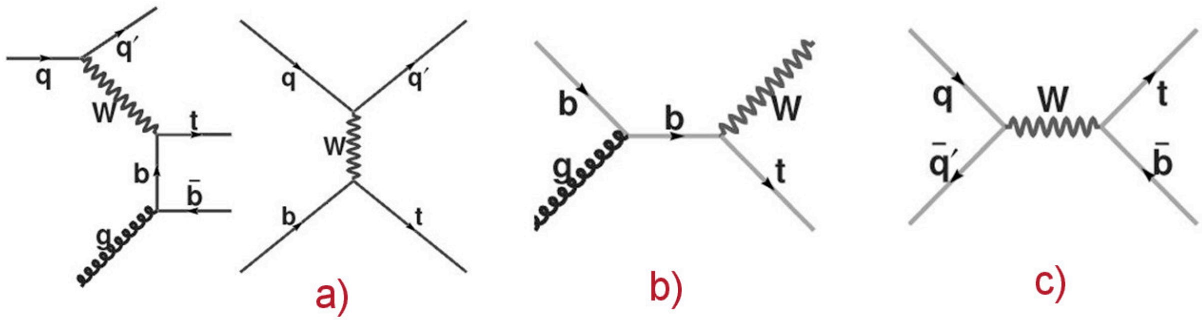

Figure 2: Main graphs corresponding to the three production mechanisms of single-top quark events: (a) t-channel (b) Wt associated production (c) s-channel.

Source	Analysis of 1 fb^{-1}		
	Variation	Cut-based	BDT
Data Statistics		5.0%	5.7 %
MC Statistics		6.5 %	7.9%
Luminosity	5%	18.3 %	8.8%
b-tagging	5%	18.1 %	6.6%
JES	5%	21.6%	9.9%
Lepton ID	0.4%	1.5 %	0.7%
Trigger	1.0%	1.7 %	1.7%
Bkg x-section		22.9%	8.2%
ISR/FSR	+7.2 -10.6%	9.8 %	9.4%
PDF	+1.38 -1.07%	12.3 %	3.2%
MC Model	4.2%	4.2 %	4.2%
Total		45%	22%

Also a reasonable measurement of V_{tb} can be extracted

The relative uncertainty on V_{tb} is the relative uncertainty on $|V_{\mathrm{tb}}|^2$ divided by two since $\delta|V_{\mathrm{tb}}|/|V_{\mathrm{tb}}| = \delta|V_{\mathrm{tb}}|^2/2|V_{\mathrm{tb}}|^2$. However, there are additional systematic uncertainties in the V_{tb} measurement due to the presence of the theoretical cross section in the denominator. Here, we quote the uncertainty calculated in [7], in which a theoretical uncertainty of $+3.8\ -4.1\%$ is reported including the contributions due to the strong scale, PDF and top quark mass uncertainties. We use the average of the positive and the negative uncertainties. Therefore, the estimated uncertainty on the measured value of V_{tb} is

$$\frac{\Delta|V_{\mathrm{tb}}|}{|V_{\mathrm{tb}}|} = \pm 11\%_{stat+sys} \pm 4\%_{theo} = \pm 12\%. \quad (4)$$

Top mass measurements

Precise measurement of the top quark is hard

- Not easy to quote these results in front of those who have sweated so hard at the Tevatron

First some basic cuts:

Process $1\ fb^{-1}$	Number of events	1 isolated lepton $p_T > 20$ GeV and $\not{E}_T > 20$GeV	$>= 4$ jets $p_T > 40$ GeV	2 b-jets $p_T > 40$ GeV
Signal	313200	132380	43370	15780
W boson backgrounds	9.5×10^5	154100	9450	200
all-jets (top pairs)	466480	1020	560	160
di-lepton (top pairs)	52500	16470	2050	720
single top, t channel	81500	24400	1230	330
single top, W t channel	9590	8430	770	170
single top, s channel	720	640	11	5

Try a few approaches to determine hadronic W

- the χ^2 minimization method,
- the geometric method: this method consists in choosing the two closest jets,
- choosing the two light jets that give the mass closest to the known mass of the W boson [14].

Top mass measurements

Try a few approaches to pair b-jet with hadronic W

- choose the b-jet that maximizes the hadronic top quark p_T.
- Choose the b-jet closest to the hadronic W boson.
- Choose the b-jet furthest from the leptonic W boson.

W-mass constraint for leptonic top

- solution minimizing two reconstructed top masses is chosen

Then some more cuts to reduce combinatorics

- Cut **C2**: the invariant mass of the hadronic W boson and the b-jet associated to the leptonic W boson must be greater than 200 GeV.
- Cut **C3**: the invariant mass of the lepton and the b-jet associated to the leptonic W boson must be lower than 160 GeV.

Description
$\lvert M_W^{\mathrm{rec}} - M_W^{PDG} \rvert < 2\,\Gamma_{M_W}^{PDG}$ (M_W^{rec} is the reconstructed hadronic W and $\Gamma_{M_W}^{PDG} = 2.1$ GeV
$\lvert M_W^{\mathrm{rec}} - M_W^{peak} \rvert < 2\,\sigma_{\mathrm{M_W}}$ ($\sigma_{\mathrm{M_W}} = 10.4$ GeV)
$M(W_{\mathrm{had}}, b_{\mathrm{lep}}) > 200$ GeV
$M(\mathrm{lepton}, b_{\mathrm{lep}}) < 160$ GeV
$\lvert X_1 - \mu_1 \rvert < 1.5\,\sigma_1$
$\lvert X_2 - \mu_2 \rvert < 2\,\sigma_2$

Finally, “calibration” to MC generated mass

Top mass measurements

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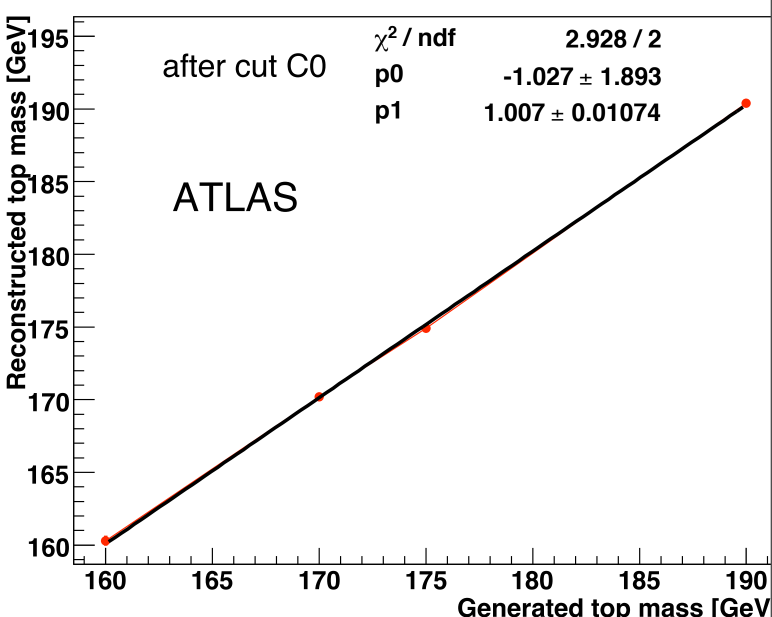
- Cut **C2**: the invariant mass of the hadronic W boson and the b-jet associated to the leptonic W boson must be greater than 200 GeV.
- Cut **C3**: the invariant mass of the lepton and the b-jet associated to the leptonic W boson mu[st] be lower than 160 GeV.

Description



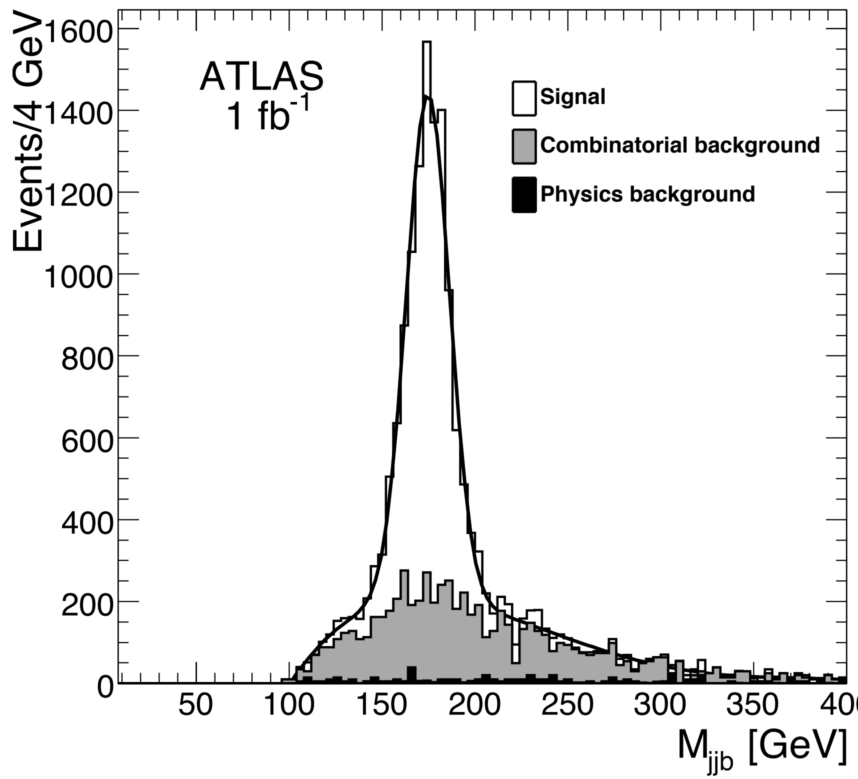
Finally, "calibration" to MC generated mass

Top mass expected result with 1 fb^{-1} @ 14 TeV

with this analysis will be dominated by systematics, the statistical uncertainty being already small ($\leq$0.4 GeV). The precision on the top quark mass relies mainly on the jet energy scale uncertainty: a precision of the order of 1 to 3.5 GeV should be achievable with 1 fb^{-1}, assuming a jet energy scale uncertainty of 1 to 5%. W boson sample can be extracted from the $t\bar{t}$ sample in order to constrain the light jet energy scale. The main uncertainty on the top quark mass measurement will come from the b-jet energy scale.

ble 6: Systematic uncertainties on the top quark mass measured in the semi-leptonic channel.

Systematic uncertainty	χ^2 minimization method	geometric method
Light jet energy scale	0.2 GeV/%	0.2 GeV/%
b jet energy scale	0.7 GeV/%	0.7 GeV/%
ISR/FSR	$\simeq$ 0.3 GeV	$\simeq$ 0.4 GeV
b quark fragmentation	$\leq$ 0.1 GeV	$\leq$ 0.1 GeV
Background	negligible	negligible
Method	0.1 to 0.2 GeV	0.1 to 0.2 GeV



With relaxed b-tagging assumptions uncertainty on m_t ~2 GeV with 1 fb^{-1} ... and at 14 TeV

Matrix Element Method

Matrix-element likelihood:
Calculate probability directly

P(event z | SM) = P (z | process A) + P(z | process B) + ...

where

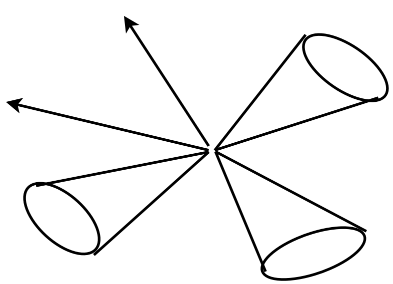
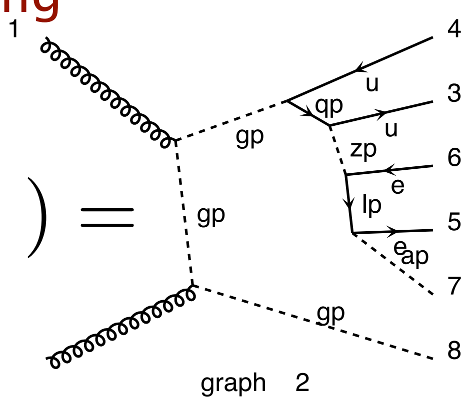
$$P(\, z \mid A\,) = \int dy\ |\mathcal{M}_A|^2 f_p f_p\ f_{TF}(y,z) \ = \ d\sigma_A/dz$$

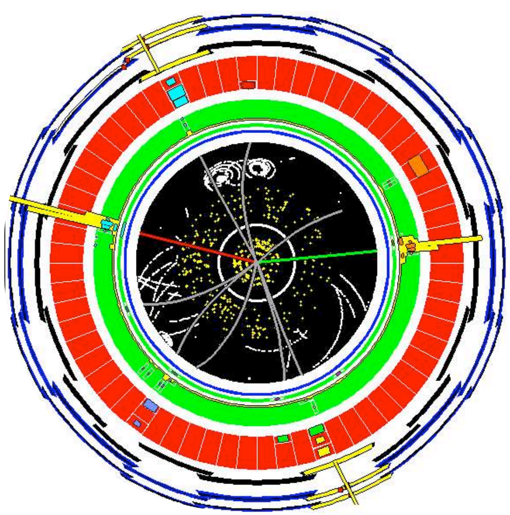
Parton(y) to detector(z) transfer function (TF) describes parton-shower and detector response in parametrized form *(Issue 2)*

Matrix-element*PDFs for process A *(Issue 2)*

Integration over parton-level quantities

- could use Sudakov factor directly
- or a new “M.E.-P.S.” method, that incorporates shower and matching

$P($  $) =$ 

$\oplus$ 

Matrix Element Method

One of the most elegant and powerful ways to extract lagrangian parameters (ie. top mass) is via the “Matrix Element” technique

- requires reasonable description of detector response
- integrate over phase space and evaluate likelihood per event

One issue... what about soft radiation? D0 boosted to the tT rest frame and added a term to the likelihood representing probability for this amount of radiation

- could use Sudakov factor directly
- or a new “M.E.-P.S.” method, that incorporates shower and matching

Matrix-element likelihood:
Calculate probability directly

P(event z | SM) = P (z | process A) + P(z | process B) + ...

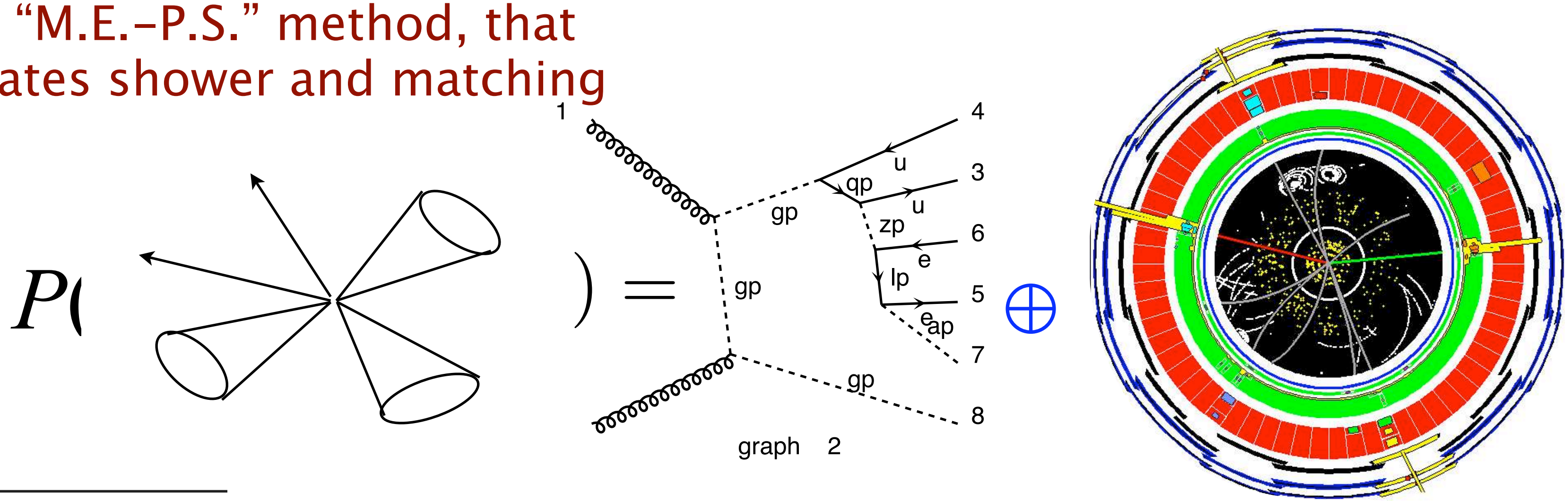
where

$$P(z \mid A) = \int dy \, |\mathcal{M}_A|^2 f_p f_{\bar{p}} \, f_{TF}(y,z) = d\sigma_A/dz$$

Parton(y) to detector(z) transfer function (TF) describes parton-shower and detector response in parametrized form *(Issue 2)*

Matrix-element*PDFs for process A *(Issue 2)*

Integration over parton-level quantities



Calibrating the Matrix Element

D0 matrix-element analysis found that the “fitted m_{top}” (in matrix element) needed to be ‘calibrated’ to “true m_{top}” used in simulation

- more indication that what was measured was the input parameter in the MC

$$
\begin{aligned}
&P_{\rm sig}(x;\, m_{\rm top}, JES) \qquad (11)\\
&= \frac{{\rm d}\sigma(p\bar{p} \to t\bar{t} \to x;\, m_{\rm top}, JES)}{\sigma_{\rm obs}(p\bar{p} \to t\bar{t};\, m_{\rm top}, JES)}\\
&= \frac{1}{\sigma_{\rm obs}(p\bar{p} \to t\bar{t};\, m_{\rm top}, JES)}\\
&\quad \times \int_{q_1, q_2, y} \sum_{\substack{q_1,\, q_2\\ \text{flavors}}} {\rm d}q_1 {\rm d}q_2 f(q_1) f(q_2)\\
&\qquad\qquad \frac{(2\pi)^4 \left|\mathscr{M}(q\bar{q} \to t\bar{t} \to y)\right|^2}{q_1 q_2 s} {\rm d}\Phi_6\\
&\qquad\qquad W(x, y;\, JES)\ .
\end{aligned}
$$

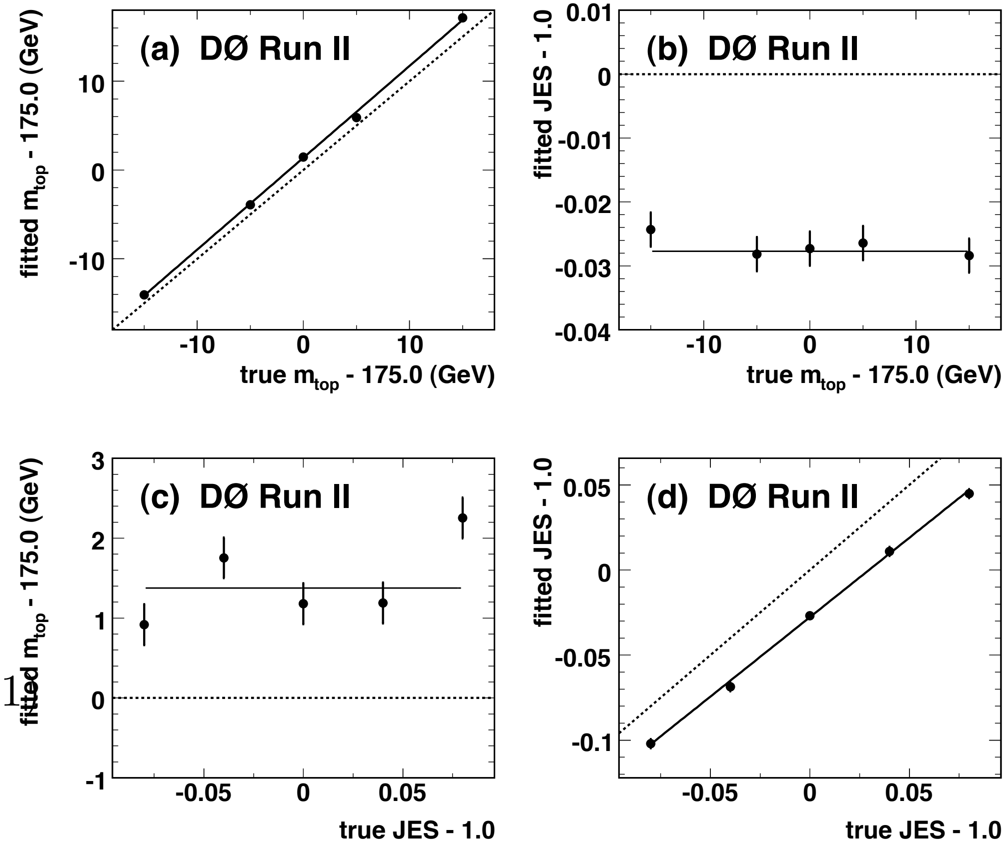


FIG. 7: Calibration of the Matrix Element mass fitting procedure for the topological analysis. The upper plots show the reconstructed top mass (a) and the measured jet energy scale (b) as a function of the input top mass. The two lower plots show the reconstructed top mass (c) and the measured jet energy scale (d) as a function of the input jet energy scale. The solid lines show the results of linear fits to the points, which are used to calibrate the measurement technique. The dashed lines would be obtained for equal fitted and true values of $m_{\rm top}$ and JES.

Anti-kT

In addition to infra-red and collinear safety, experimentalists want jets that are ‘easy to understand’ (in the sense of calibration, sensitivity to pileup, etc.)

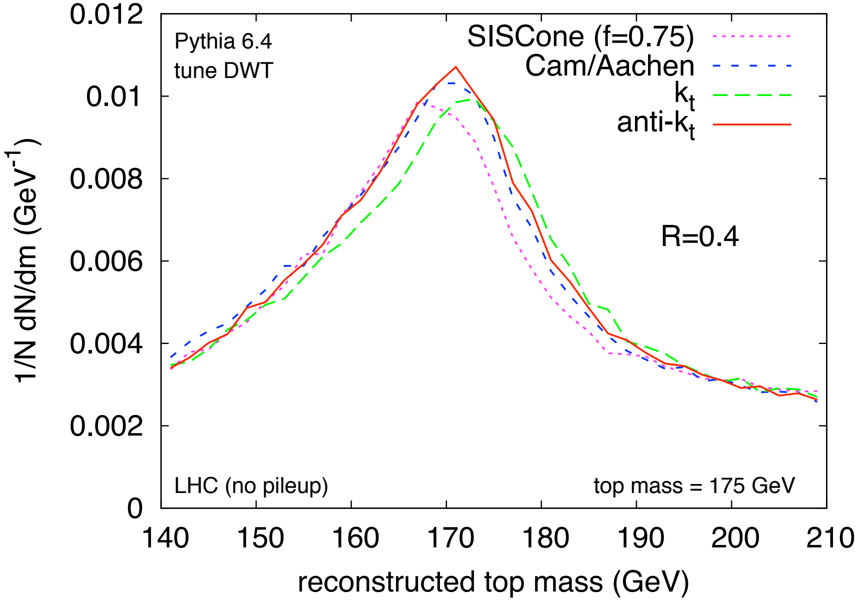
- kT and C/A have been hard b/c of sensitivity of boundary to soft stuff

Anti-kT expands the space of the recombination jet algorithms with p<0

- many nice properties, ATLAS is moving this direction.
- impact on top mass?

$$d_{ij} = \min(k_{ti}^{2p}, k_{tj}^{2p}) \frac{\Delta_{ij}^2}{R^2} ,$$

$$d_{iB} = k_{ti}^{2p} ,$$



Cacciari, Salam, Soyez JHEP04(2008)063

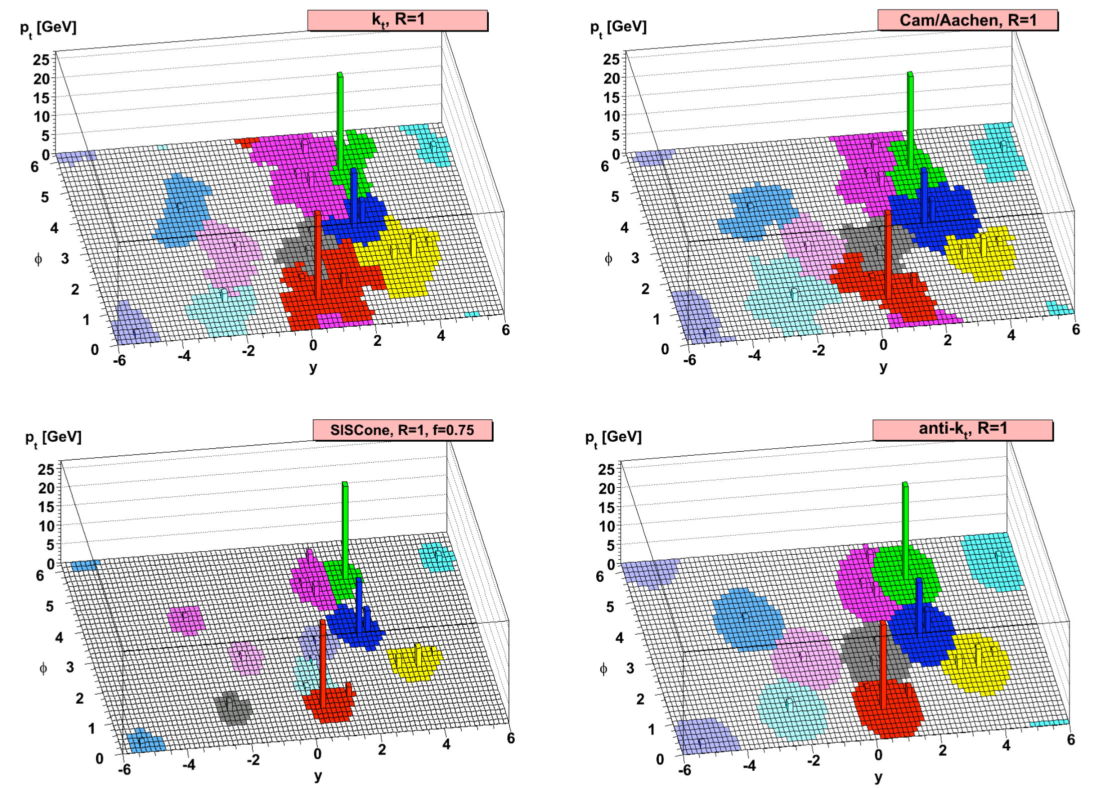


Figure 1: A sample parton-level event (generated with Herwig [8]), together with many random soft “ghosts”, clustered with four different jets algorithms, illustrating the “active” catchment areas of the resulting hard jets. For k_t and Cam/Aachen the detailed shapes are in part determined by the specific set of ghosts used, and change when the ghosts are modified.

Top properties

Several results here, and I don't want the talk to turn into a laundry list

- please see resources or ask if you are interested in a particular results:
  - top charge
  - anomalous couplings at Wtb vertex
  - W-boson polarization
  - top-anti-top correlations
  - Flavor Changing Neutral Currents

Instead,

- Show top charge, could be done fairly early
- Address some specific issues

Top Charge

An exotic top with charge 4/3 could be excluded fairly early on

- select events where correct lepton-b pairing is pure (~85%)

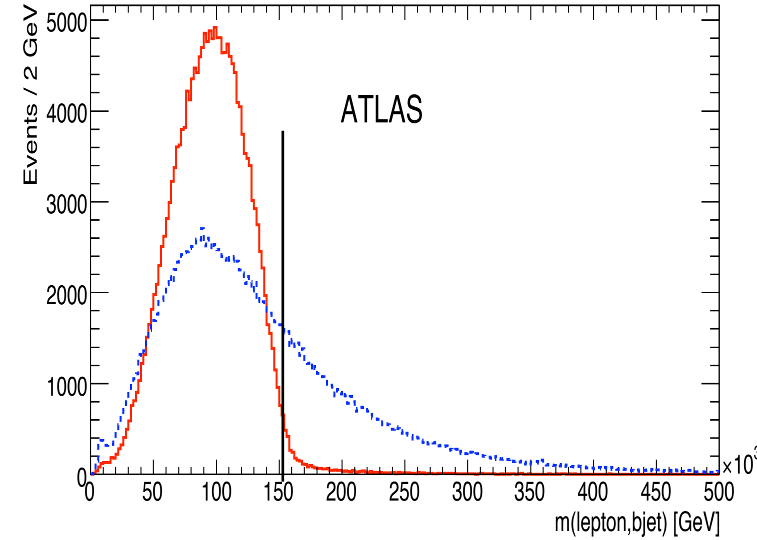
$$m(l, b_{\text{jet}}^{(1,2)}) < m_{\text{cr}} \quad \text{and} \quad m(l, b_{\text{jet}}^{(2,1)}) > m_{\text{cr}}$$

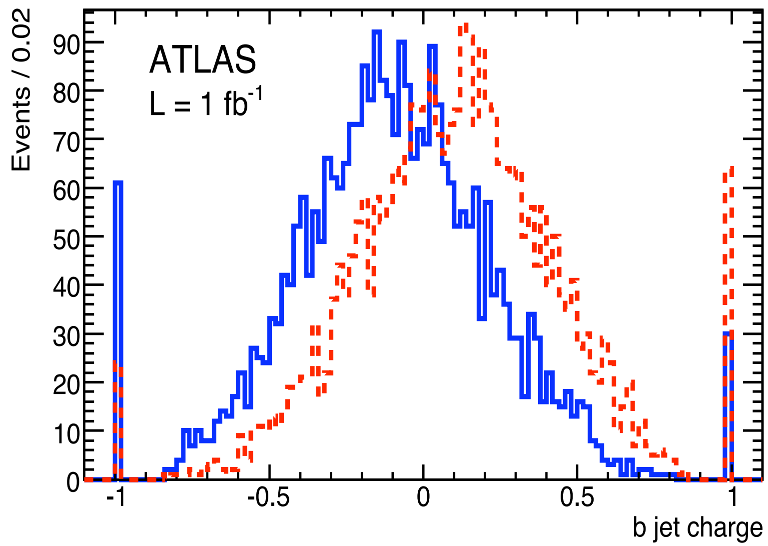
- use "jet charge" or semi-leptonic b-decay to tag b or bbar

$$Q_{\text{bjet}} = \frac{\sum_i q_i |\vec{j}_i \cdot \vec{p}_i|^\kappa}{\sum_i |\vec{j}_i \cdot \vec{p}_i|^\kappa}$$

  - jet charge needs calibration from mean to 1/3 (determined from data)

$$Q_t = Q(\ell^+) + Q_{b\,jet}^{(+)} \times C_b\,, \qquad Q_{\bar{t}} = Q(\ell^-) + Q_{b\,jet}^{(-)} \times C_b$$



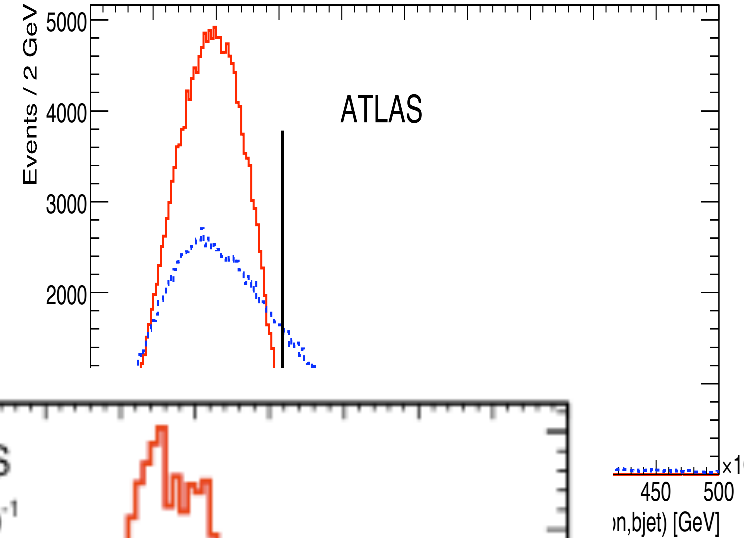


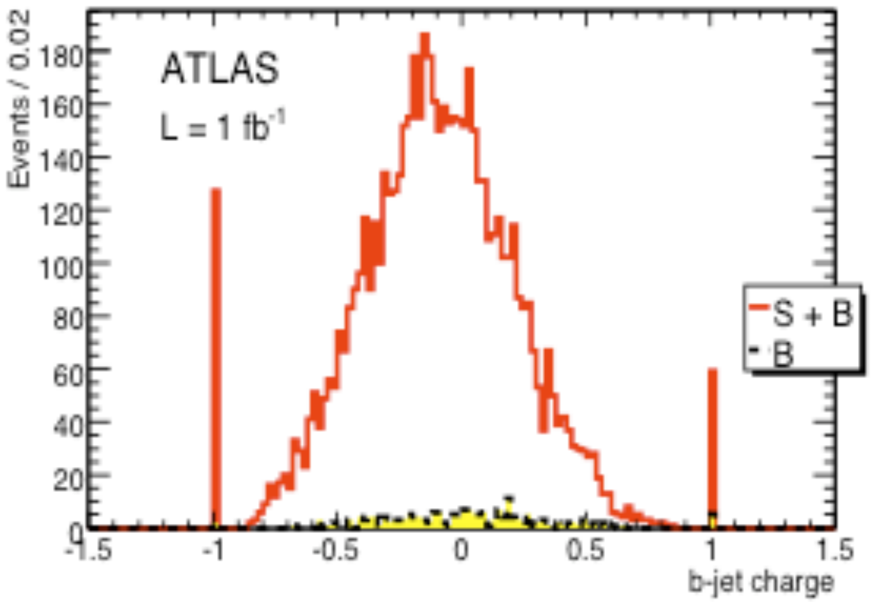
$$Q_t^{\text{comb}} = 0.67 \pm 0.06\ (\text{stat}) \pm 0.08\ (\text{syst})$$

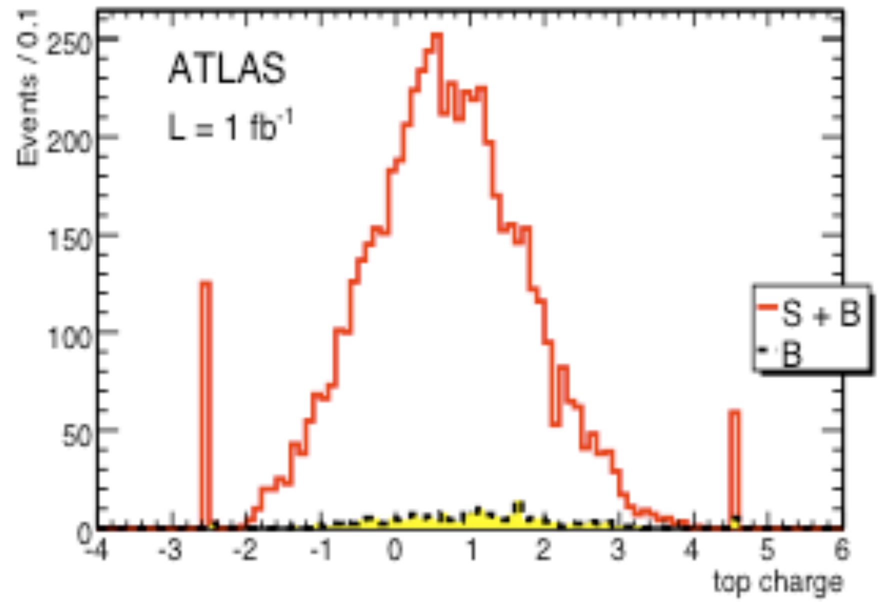
Top Charge

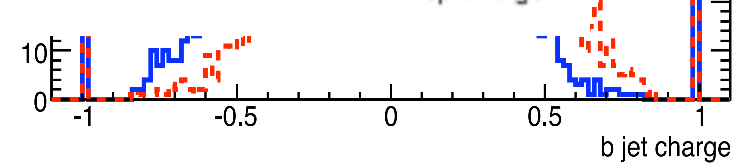
An exotic top with charge 4/3 could be excluded fairly early on

- select events where correct lepton-b pairing is pure (~85%)









$$Q_t = Q(\ell^+) + Q_{b\,jet}^{(+)} \times C_b\,, \qquad Q_{\bar{t}} = Q(\ell^-) + Q_{b\,jet}^{(-)} \times C_b$$

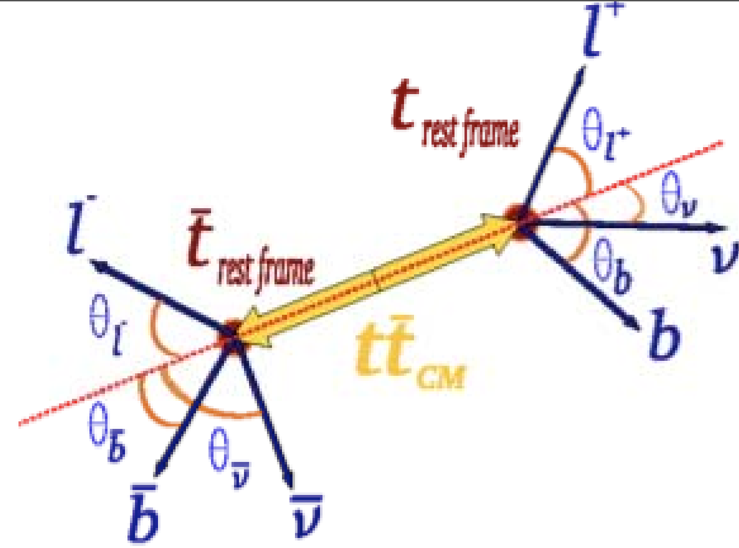
$$Q_{\mathrm{t}}^{\mathrm{comb}} = 0.67 \pm 0.06\ (\mathrm{stat}) \pm 0.08\ (\mathrm{syst})$$

top- anti-top correlations

- Angle θ defined between top quark direction in t-tbar rest frame, and decay product in t rest frame

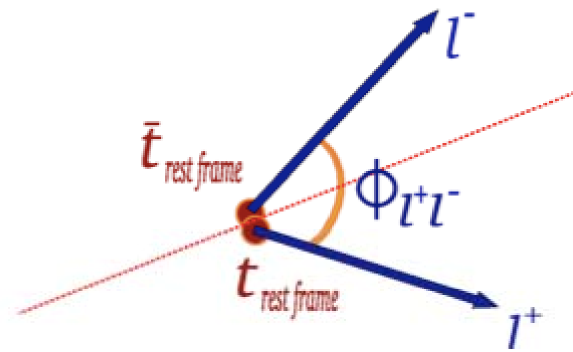
$$\frac{1}{N}\frac{d^2N}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}(1 - A|\alpha_1\alpha_2|\cos\theta_1\cos\theta_2)$$

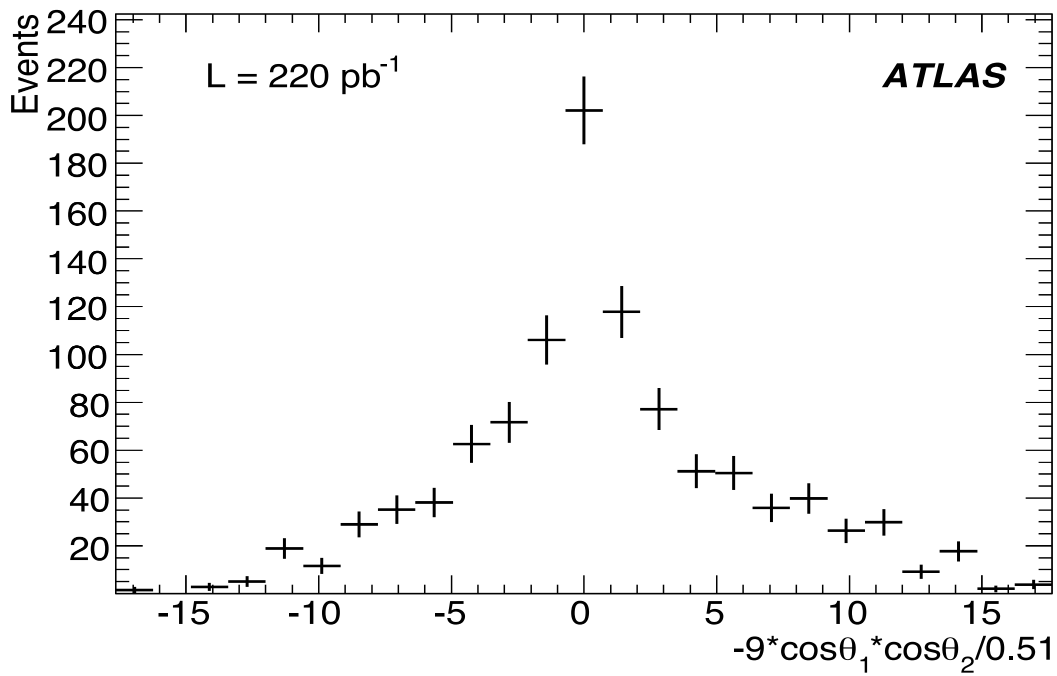
- θ_1, θ_2 measured using a decay product from each top quark 1,2; α_1, α_2 are analysing powers
  - α: Correlation between top and decay product
  - 1 for lepton; -0.41 for b, 0.51 for lower E q from W



- Can also look at opening angle
  - Useful in particular for dileptons

$$\frac{1}{N}\frac{dN}{d\cos\Phi} = \frac{1}{2}(1 - A_D|\alpha_1\alpha_2|\cos\Phi)$$





31st March 2009 Richard Hawkings 6

Expt	Measurement	Int L	stat	syst
ATLAS	A(q-l) ≈ 0.42	1 fb^{-1}	0.17	0.18
ATLAS	A_D(q-l) ≈ -0.29	1 fb^{-1}	0.11	0.09

top- anti-top correlations

- Angle θ defined between top quark direction in t-tbar rest frame, and decay product in t rest frame

$$\frac{1}{N}\frac{d^2N}{d\cos\theta_1 d\cos\theta_2} = \frac{1}{4}(1 - A|\alpha_1\alpha_2|\cos\theta_1\cos\theta_2)$$

- θ_1, θ_2 measured using a decay product from each top quark 1,2; α_1, α_2 are analysing powers
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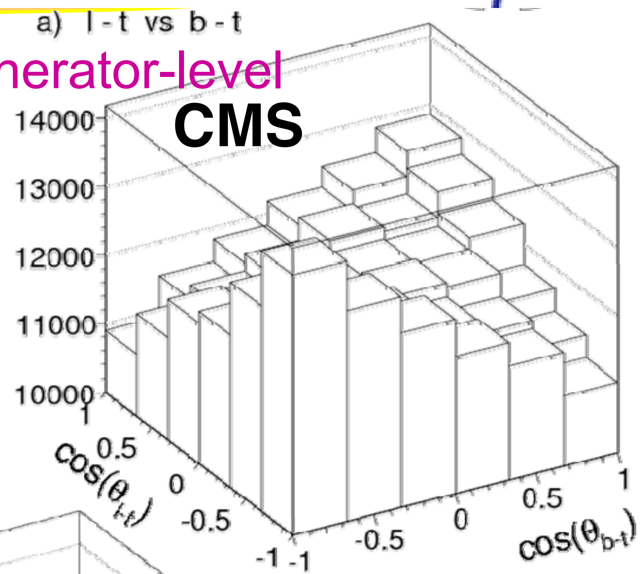
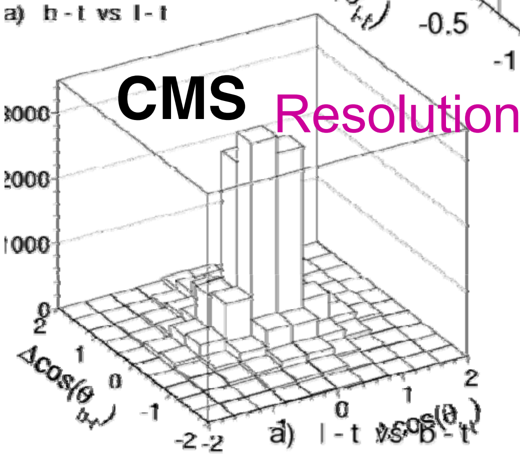
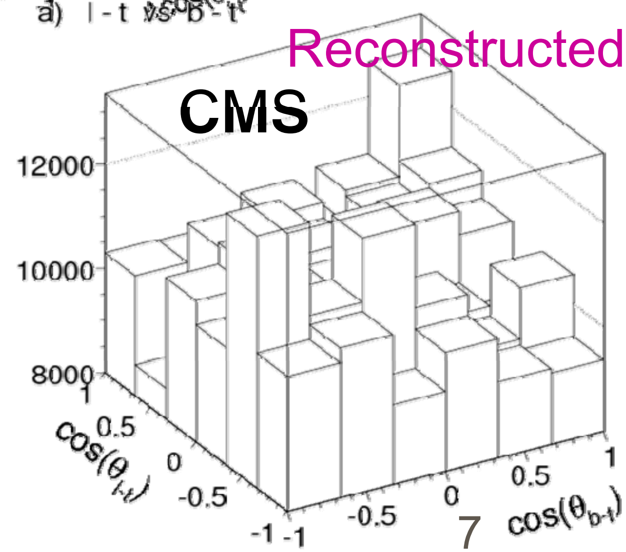
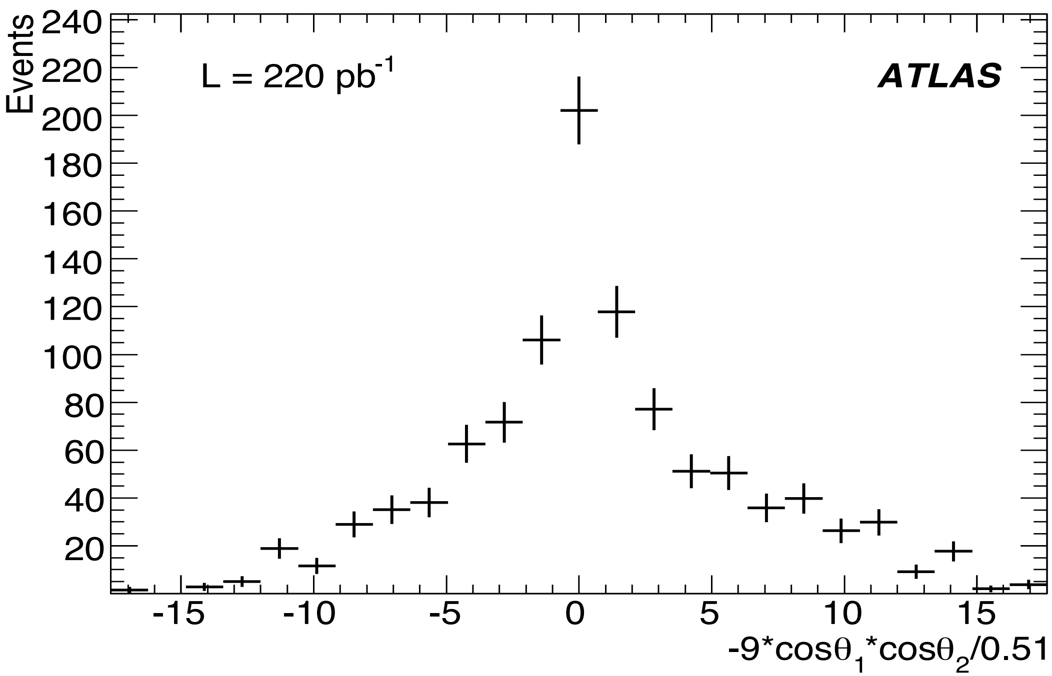




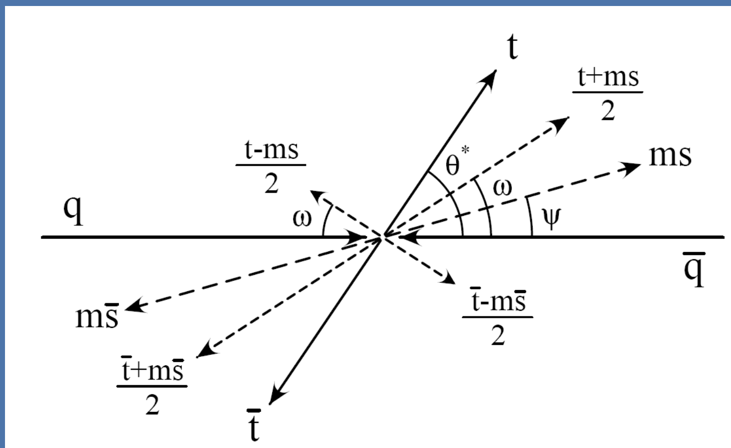




7

Comment on spin-correlations

In the qq initiated sub-process, the spin of the top and the anti-top are correlated because the intermediate particle is a vector (gluon).

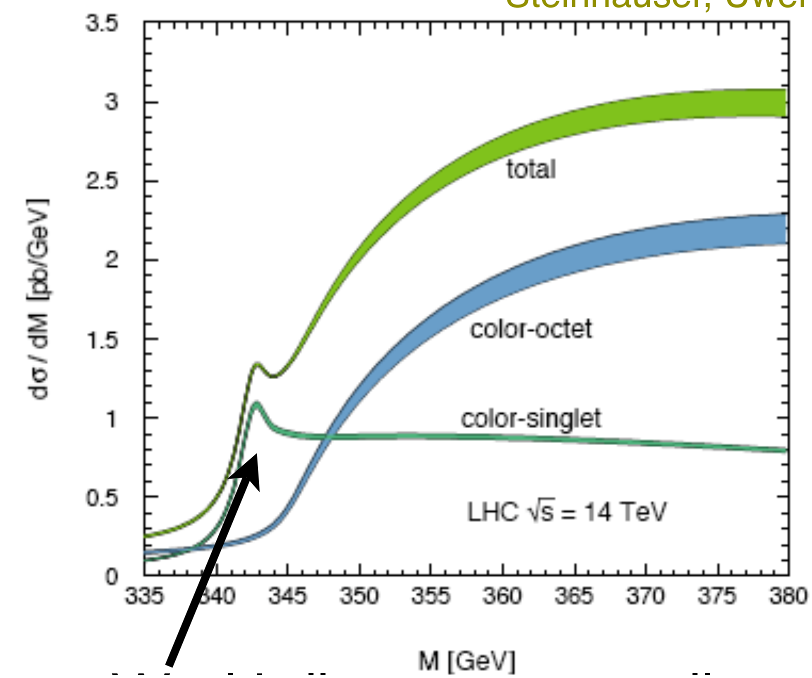


G Mahlon S Parke
PLB411, 173 (1997)

At Tevatron, q qbar dominates and the optimal basis results in a 92% spin correlation.

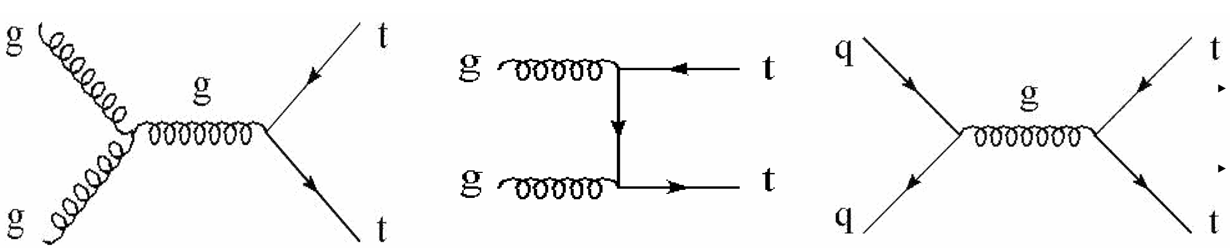
At LHC, the effect is somewhat washed out by the dominance of the gg initial state.

Kiyo, Kuehn, Moch, Steinhauser, Uwer



An idea while putting this together, different M_{tt} ranges have big differences in octet/singlet ratio.

- I would expect this to imply different ratios of gg vs. qQ initiated sub-processes.
- indeed sensitive to cut at ~550 GeV
- can we enhance the effect with a lower cut on M_{tt}?



Top and Higgs

One of the interests in top is it's important role in electroweak symmetry breaking (EWSB).

- There are many new physics scenarios that use this as motivation,
- but there is also an important role for top in the Standard Model Higgs that deserves some (more) attention

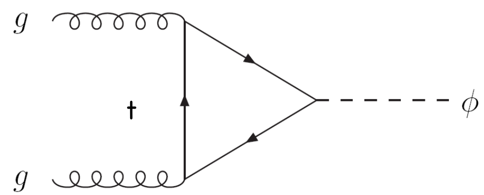
An example abstract for ATLAS/CMS proceedings...

The $t\bar{t}H$ analyses at the LHC

Summary. — Detecting the presence of a light Higgs boson at the LHC is very difficult. For this reason, different experimental signatures will have to be combined to ensure its discovery. Among them we study the associate production with a pair of top quarks and the subsequent Higgs boson decay into b quark pairs, the dominant decay mode for $m_H \lesssim 135\,\mathrm{GeV}/c^2$. This channel allows an accurate estimation of the top quark Yukawa coupling within the Standard Model. We present several observability studies of the $t\bar{t}H(\to bb)$ channel with the ATLAS and the CMS detectors. In addition, the decay modes $H \to WW$ and $H \to \gamma\gamma$ in $t\bar{t}H$ processes have been investigated and are briefly reported at the end of this paper.

Top and Higgs

While it is true that you can get at the top-Higgs Yukawa through this channel, that is also true for Higgs produced via gluon fusion (eg. and decay to photons):



The important aspect of ttH(->bb) is one of the only ways you can measure the **bottom**-Higgs Yukawa coupling

- I pick on this because so much effort goes into trying to optimize ttH for discovery, but not much into measuring this coupling.

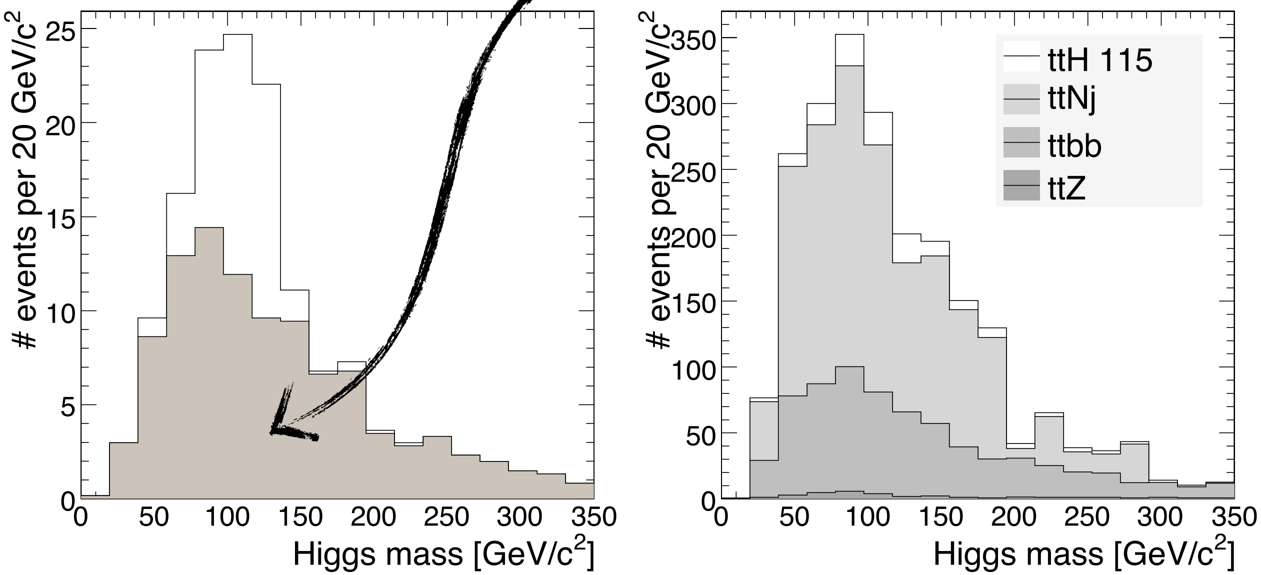
coupling. Because this mode dominates Higgs decays at low mass ($m_H \lesssim 135$ GeV within the SM), an accurate measurement of the bottom Yukawa coupling is extremely important. Unfortunately, due to the typically large QCD backgrounds for b jets, it is very difficult to observe this decay. The production modes $t\bar{t}H$ [27,32,33] and WH [14,34] might allow very rough measurements for such a light Higgs, but the statistical significances are quite low and the background uncertainties quite large and their rates probably underestimated; they are definitely high-luminosity measurements.

[Duhrssen, et al, Phys.Rev.D70:113009, 2004]

Top and Higgs

Interestingly, the main backgrounds to ttH are also top

- ttH signal provides combinatoric background



- ttbb (theoretically challenging)
- ttjj with jets mis-tagged, challenging to estimate this background both theoretically and experimentally

With low S/B and high uncertainty on B, this channel looks hopeless for discovery and maybe even observation

What if analysis were tuned for measurement instead of discovery?

From the ashes

... Or what if you have a clever idea instead

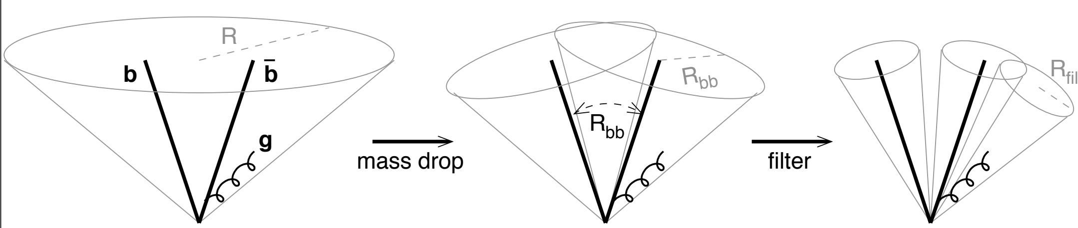
Jet substructure as a new Higgs search channel at the LHC

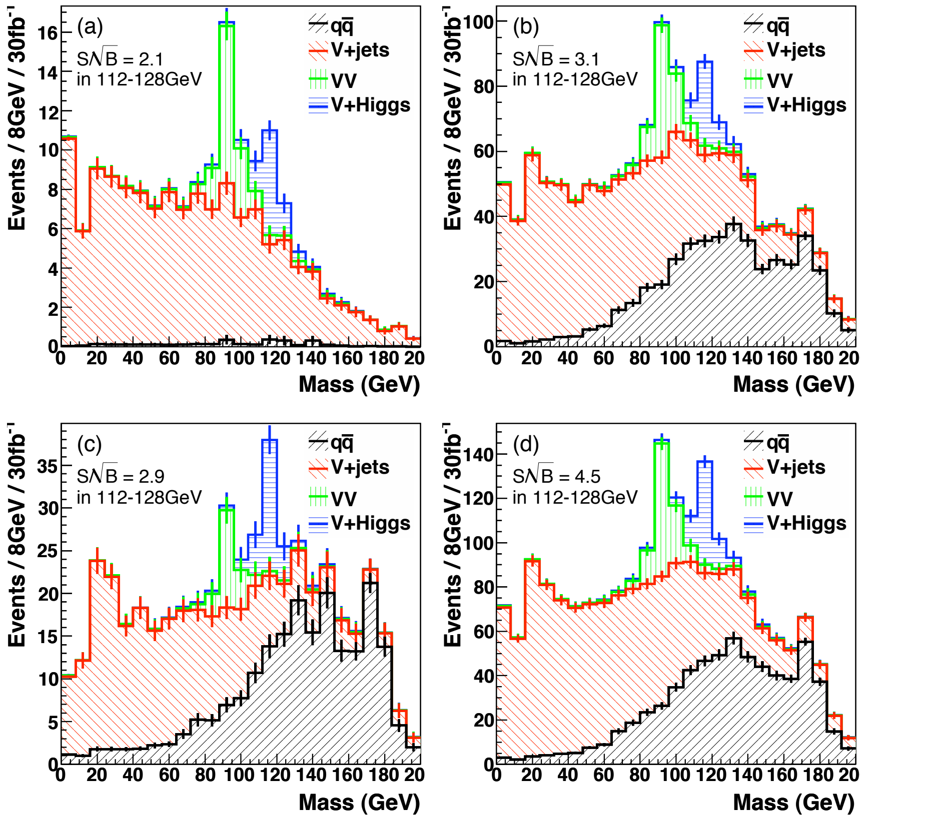
Jonathan M. Butterworth, Adam R. Davison
Department of Physics & Astronomy, University College London.

Mathieu Rubin, Gavin P. Salam
LPTHE; UPMC Univ. Paris 6; Univ. Denis Diderot; CNRS UMR 7589; Paris, France.

It is widely considered that, for Higgs boson searches at the Large Hadron Collider, WH and ZH production where the Higgs boson decays to $b\bar{b}$ are poor search channels due to large backgrounds. We show that at high transverse momenta, employing state-of-the-art jet reconstruction and decomposition techniques, these processes can be recovered as promising search channels for the standard model Higgs boson around 120 GeV in mass.

PhysRevLett.100.242001 (2008)





Recent advances in using jet substructure have made WH and ZH channels with H->bb look promising

- Similar ideas for jet substructure were previously proposed for highly boosted top

$$R_{b\bar{b}} \simeq \frac{1}{\sqrt{z(1-z)}} \frac{m_{\mathrm{H}}}{p_T},$$

Z' -> tT

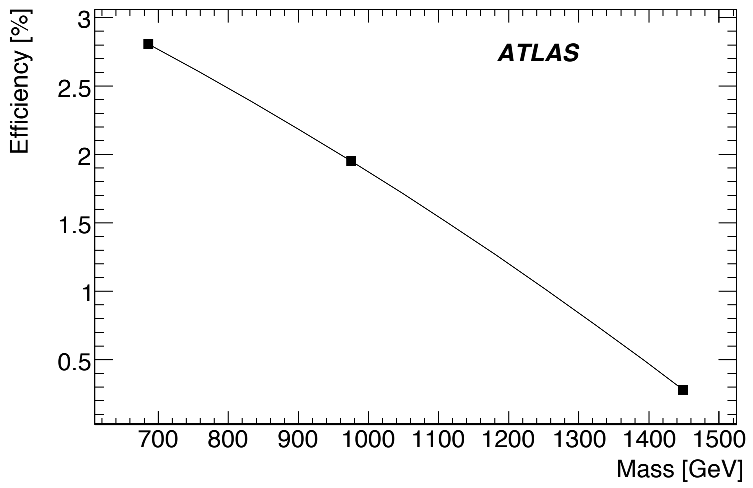


Figure 13: Reconstruction efficiency of Standard Model $t\bar{t}$ pairs as a function of the $t\bar{t}$ mass.

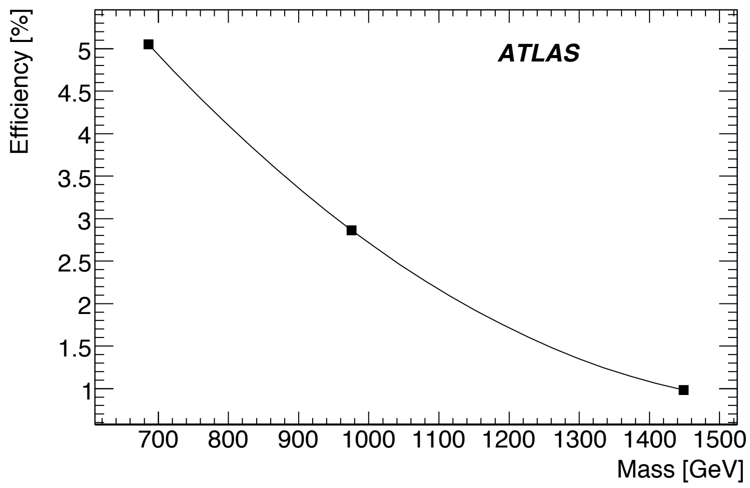


Figure 14: Reconstruction efficiency of $Z' \to t\bar{t}$ resonances as a function of the Z' mass.

Looked at a "generic" narrow resonance decaying to top pairs.

- jet pairing was based on ΔR and b-tagging

At high Z' mass, the products start to merge

- efficiencies drop, need something new

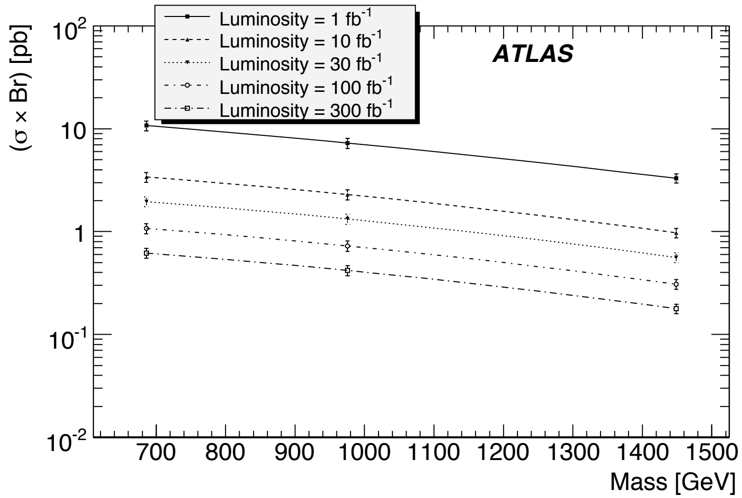
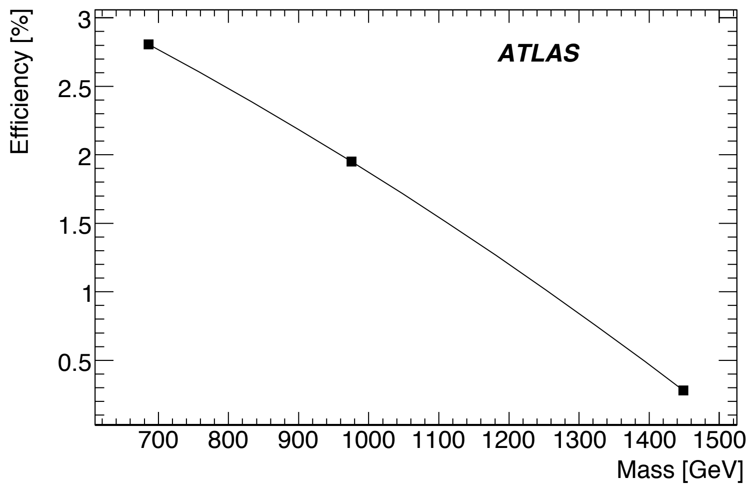


Figure 16: 5σ discovery potential of a generic narrow $t\bar{t}$ resonance as a function of the integrated luminosity.

Z’ -> tT



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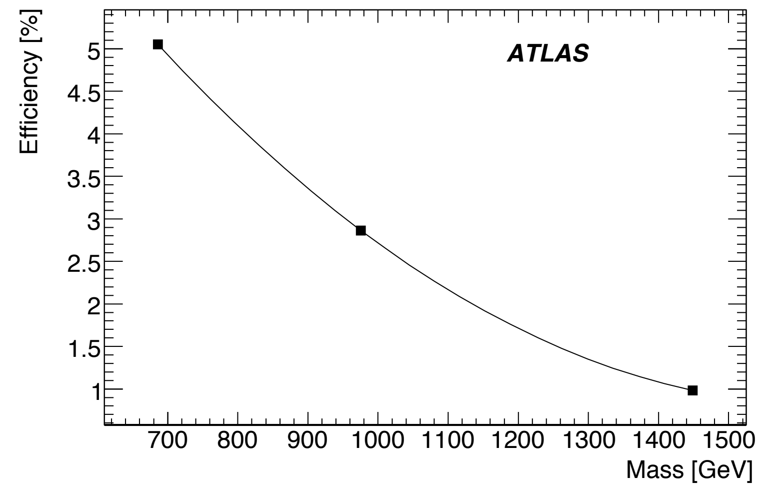

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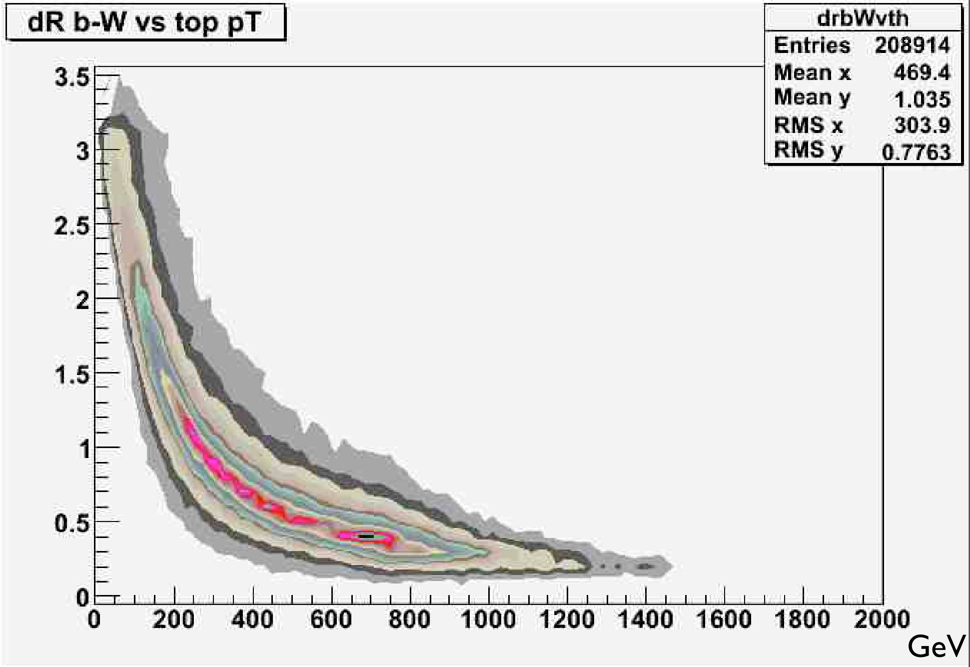
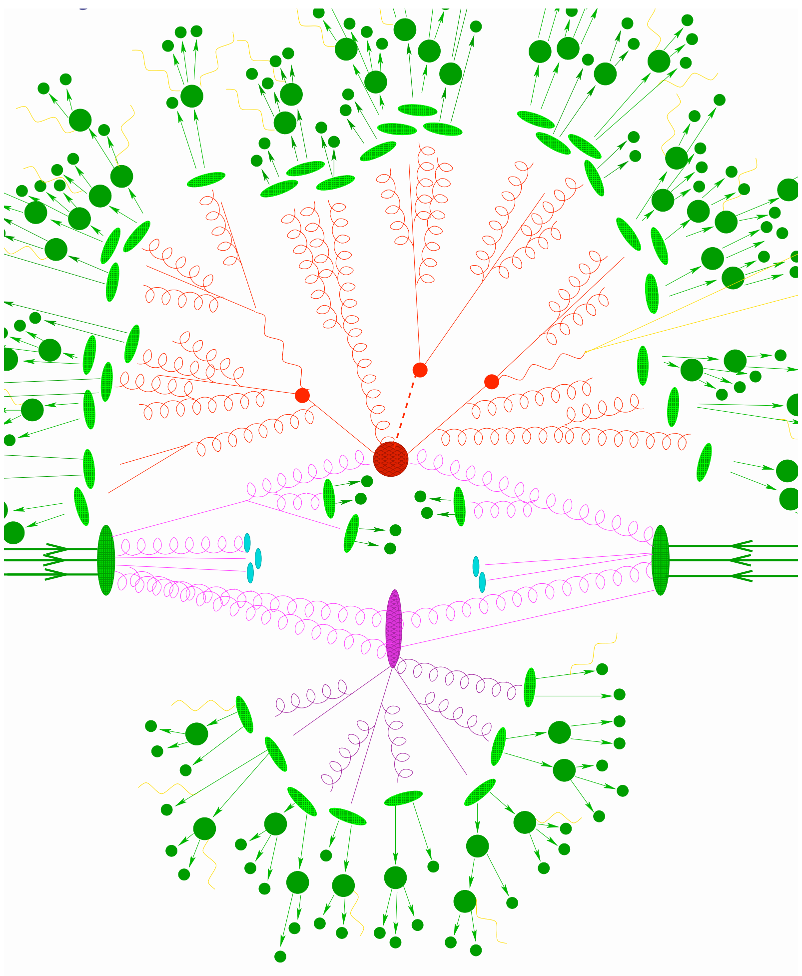


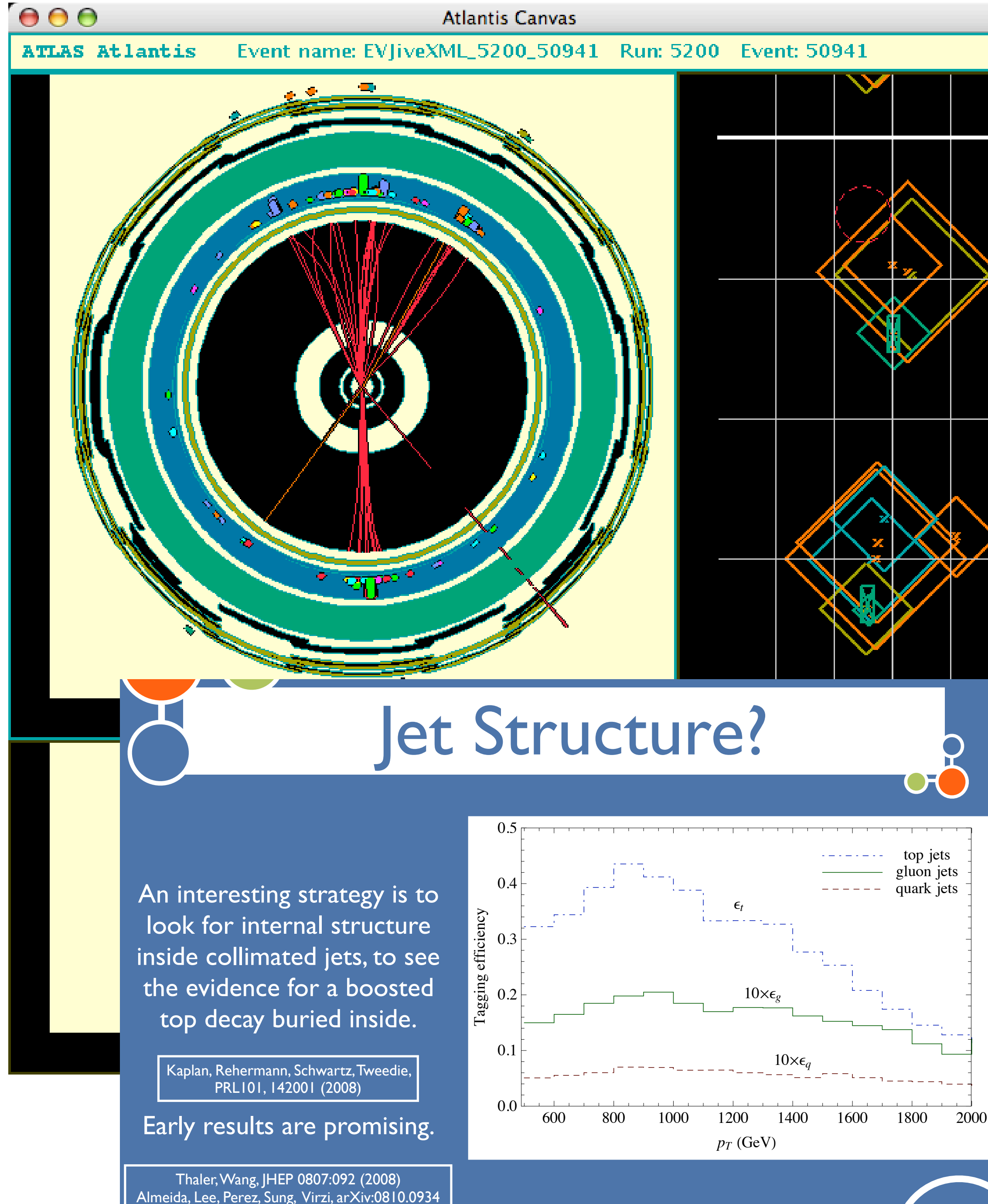
minosity.

Jet Substructure

A lot of activity by theorists and experimentalists in boosted tops. Idea:

- jet substructure





Don't forget about the shower in the calorimeter

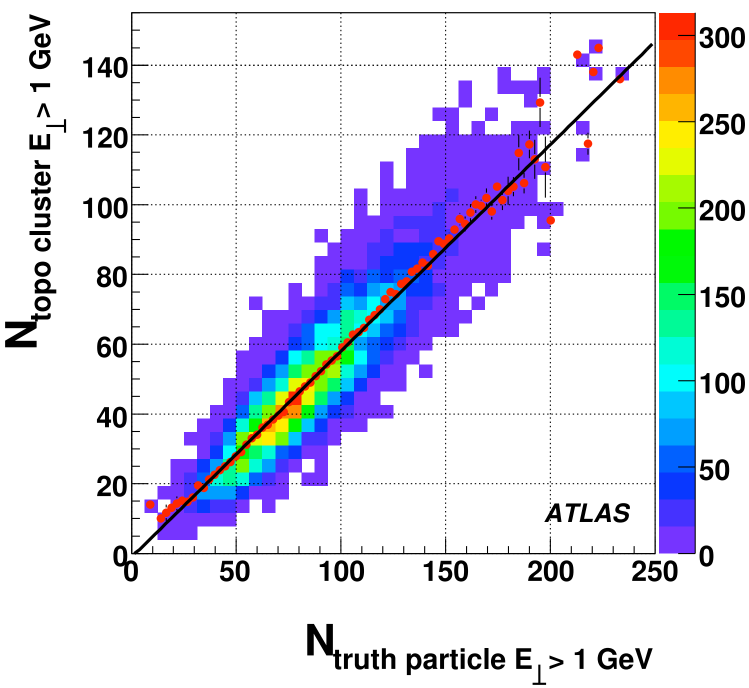
Not complaining about theorist's particle-level analyses, but

- in addition to calorimeter granularity, but hadronic shower also has size
- and clustering merge several showers into one cluster
- and towers can split one shower into several towers

For our particular implementation, we simulate dijet events and $t\bar{t}$ events in the standard model at the LHC using PYTHIA V.6.415 [11]. In order to simulate the resolution of the ATLAS or CMS calorimeters, particles in each event are combined into square bins of size $\Delta\eta = \Delta\phi = 0.1$, which are interpreted as massless four-vector "particles" and inputted into the clustering routine. For jet

Optimization should include the pre-clustering, jets, and leverage EM core of showers in addition to jet substructure

1 cluster corresponds to 1.6 truth particles



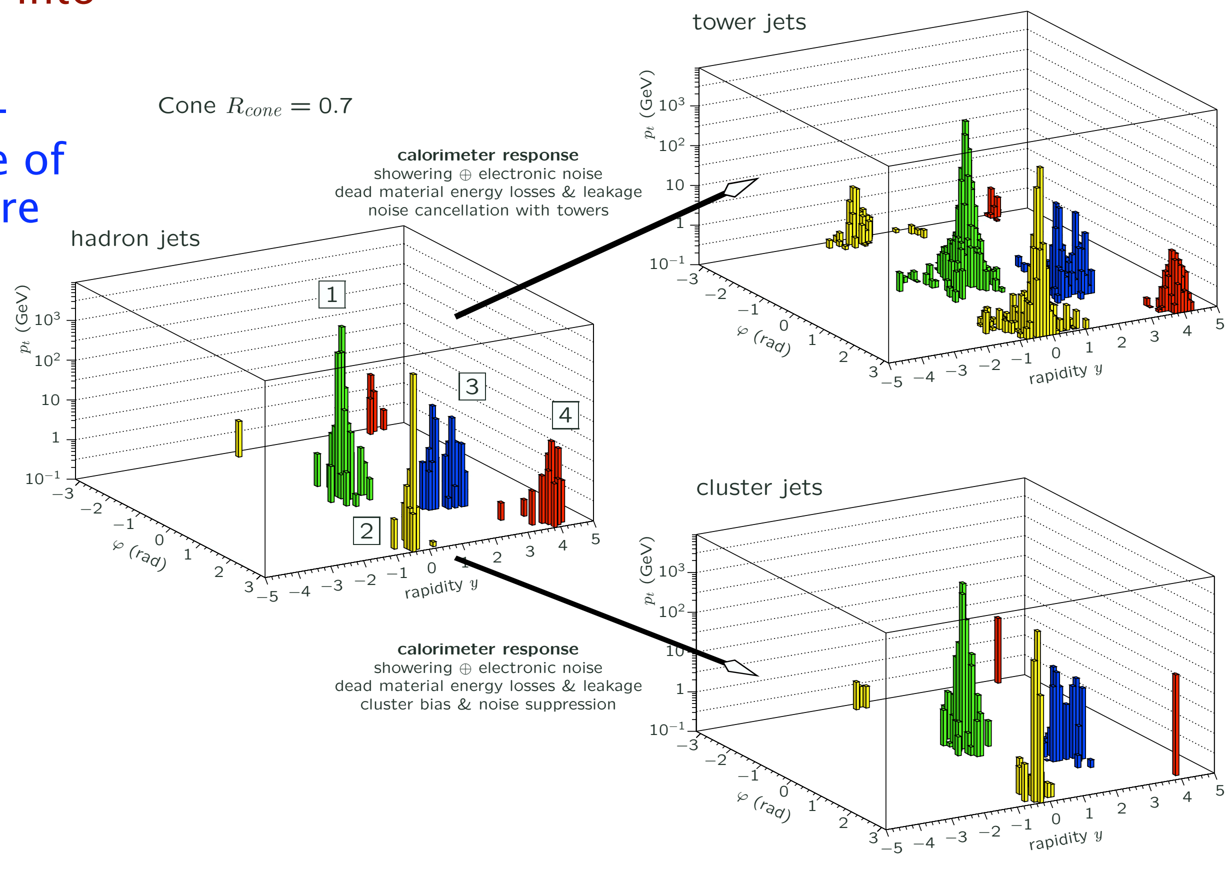


Figure 5: A simulated QCD dijet event with four jets in the final state, as seen at particle level and in the ATLAS calorimeters when using towers or clusters (extracted from Ref. [16]).

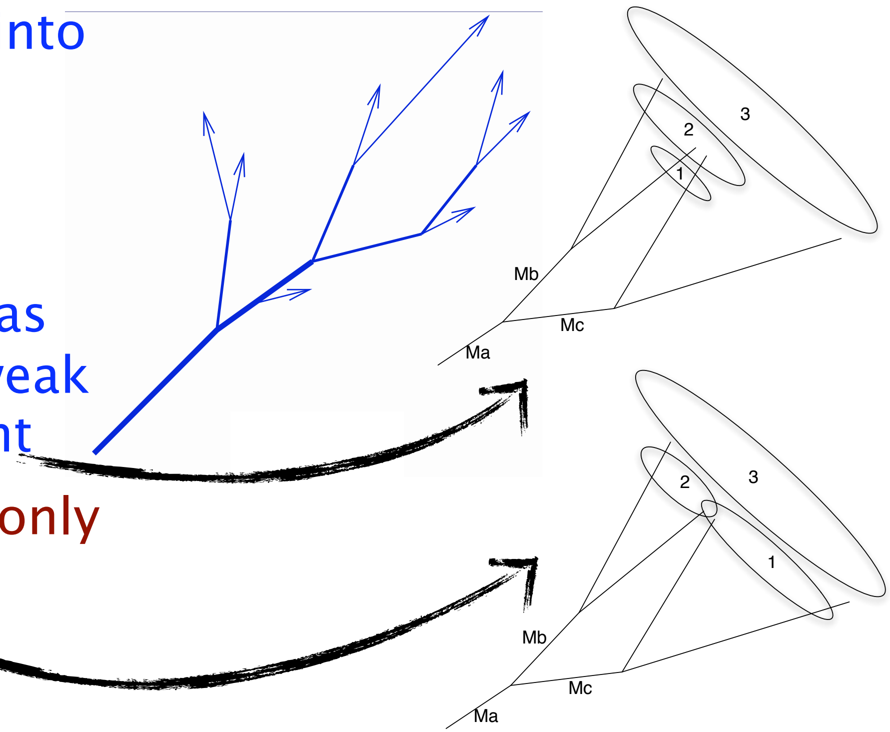
Jet Substructure ATLAS

One examines the substructure by looking into the scales associated with the kT clustering steps

- seems to work quite well

Idea/comment: the original jet clustering was motivated on parton shower evolution. A weak decay of a massive particle is pretty different

- could we construct a jet algorithm that only clusters under the constraint of a hypothesized massive object inside



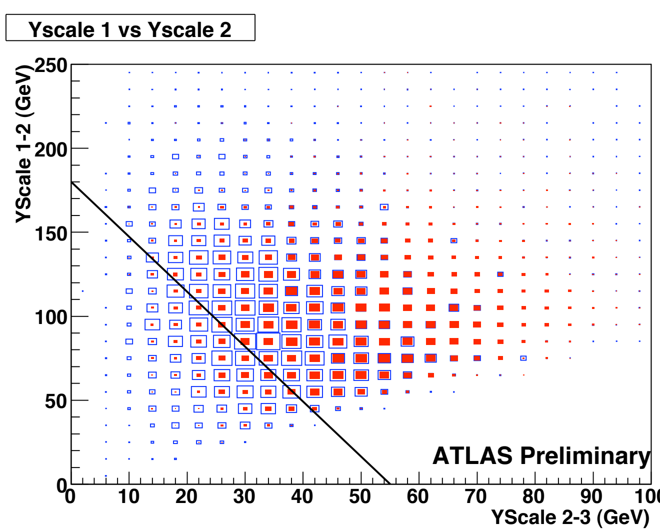
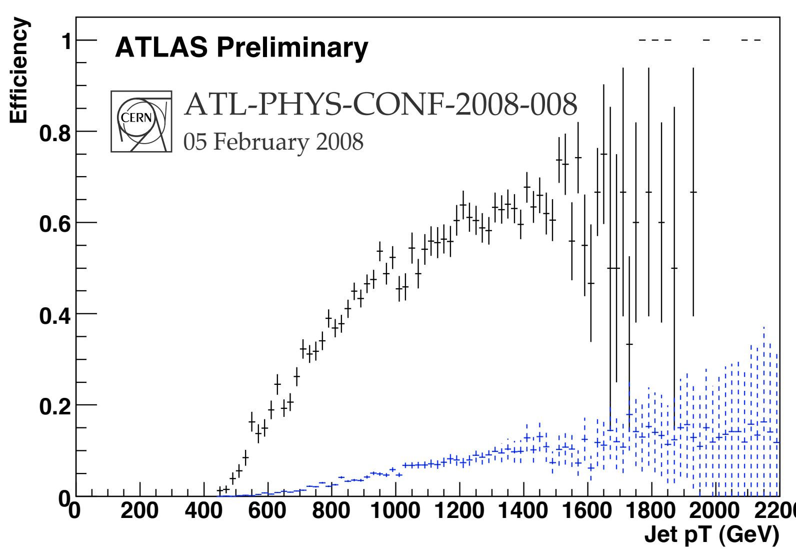


Figure 13: Distribution of $YScale_{12}$ as a function of $YScale_{23}$ for the background (blue/open) and signal (red/filled) samples. Events are required to lie above the line.



Conclusions

Top quark physics at the LHC is very rich and promises to be very fruitful

- expectations for the LHC are based on a number of assumptions about the conditions of the LHC which are currently unknown
- still, if we are able to get ~100 pb^{-1} at ~10 TeV we should be able make a few interesting measurements in the first year
- beyond that many new opportunities with ~1 –10 fb^{-1}

Even if we had that data today, there are several issues to be addressed for the theoretical community and experimental community

- finally there are a few areas where theorists and experimentalists need to sit and talk...
  - not only to understand what was done (eg. top mass)
  - but how we can do it differently to improve (eg. top mass)